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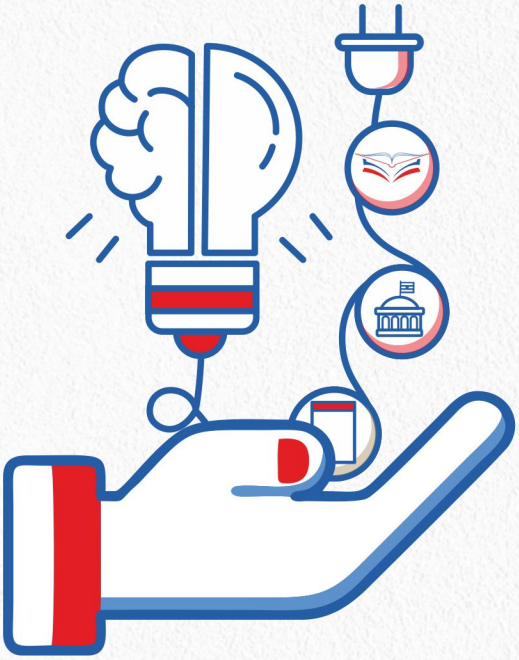
OPTIONAL SUBJECT CLASSES 2027



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SCIENCE AND TECHNOLOGY

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Preface

To the Aspirants

The UPSC Civil Services Mains Examination is not merely a test of knowledge but a challenge of precision, clarity, and smart revision. In General Studies Paper III, Science & Technology has emerged as one of the **most dynamic and scoring areas, demanding a blend of conceptual understanding and current affairs awareness**. Recognizing this, **VisionIAS bring to you Mains 365 – Science & Technology**, a meticulously curated document designed to serve as your ultimate revision companion.

This document is **not just a compilation of scientific developments and technological breakthrough**s. It is a strategic tool crafted to help aspirants enrich **answer quality, integrate contemporary developments with conceptual clarity, and secure those crucial extra marks t**hat often determine final rank. With theme-based categorization, value-added content, keywords, examples, this compilation enables comprehensive revision even during the last few days before the examination.

Let this be your go-to guide for clarity, for revision, and for success.

Q1. WHY DO ASPIRANTS FIND GS-III SCIENCE & TECHNOLOGY CHALLENGING?

- **Fragmented Sources:** Information is scattered across newspapers, scientific journals, PIB releases, government reports, and magazines.
- **Static-Dynamic Disconnect:** Understanding concepts without linking them to contemporary developments leads to superficial answers.
- **Technical Complexity**: Topics such as Quantum Computing, Gene Editing, AI, and Space Technology often appear difficult due to scientific terminology.
- **Rapid Technological Change:** Emerging technologies evolve quickly, making conventional notes outdated.

This document is designed to address these challenges.

Q2. WHY IS THIS DOCUMENT YOUR EDGE IN GS PAPER-III SCIENCE & TECHNOLOGY?

- **UPSC-Oriented Coverage:** Focuses on high-yield themes such as Artificial Intelligence, Quantum Technology, Biotechnology, Space Technology, Robotics, Nanotechnology, and Nuclear Energy.
- **Concept + Current Affairs Integration:** Most of the topic is linked with contemporary developments, missions, schemes, and innovations.
- **Ready-to-Use Frameworks:** Provides Introduction–Body–Conclusion structures for answer writing.
- **Value Addition Tools:** Infographics, keywords, examples, 'Topic at a Glance', and data points enhance answer quality.

Q3. HOW DOES IT ENHANCE ANSWER WRITING?

Let's take a Question:

"Discuss the need for National One Health Mission (NOHM) in strengthening India's public health security. Also mention key initiative taken for its effective implementation."

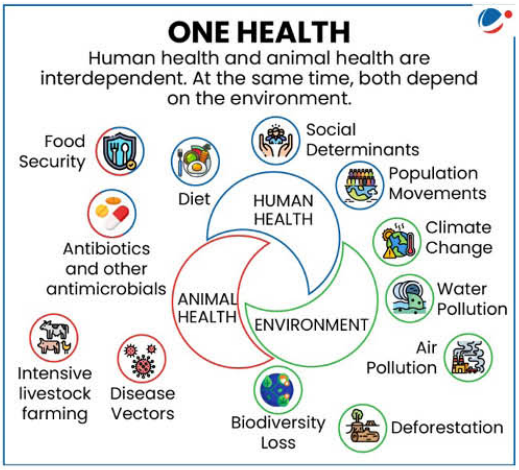
Answer Framework: This document enables you to answer such contemporary Science & Technology questions with ease and precision by

integrating scientific concepts, governance dimensions, and current affairs developments.

INTRODUCTION CAN BE ADDED FROM HERE:

About National One Health Mission

- A multi-sectorial initiative integrating human, livestock, wildlife and environmental health to strengthen coordinated surveillance, diagnostics and outbreak response.
  - **One Health Approach** is an integrated, unifying approach that aims to sustainably balance and optimize the health of people, animals, and ecosystems.
- **Anchor Institution**: National Institute of One Health, Nagpur.



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BODY PART-1 FROM HERE:

Need of National One Health Mission

- **Zoonotic Risk Mitigation:** It responds to the global evidence that nearly 60% of emerging infectious diseases are zoonotic in origin.
- **Pandemic Preparedness:** Establishes predictive and preventive health-security architecture, shifting India from a reactive response model to an anticipatory, systems-based public-health framework.
- **Climate Change Impacts**: Changing climate patterns are expanding the range of vectors like mosquitoes, increasing diseases such as dengue and malaria.

BODY PART-2 FROM HERE:

Initiatives related to one-health approach

- **Centre for One Health (CoH) at NCDC**: Coordinates efforts, runs programs (Rabies, Zoonoses, Leptospirosis, Snakebite), and promotes the One Health approach in India.
- **One Health Supporting Unit within Department of Animal Husbandry & Dairying:** Specialized team of experts established to implement the national One Health framework in India.
- **BSL-3/4 Lab Network:** A national network of high-security labs for rapid analysis of disease outbreaks across sectors.

WAY FORWARD / CONCLUSION FROM HERE:

Conclusion

The Mission marks a shift towards integrated and preventive health governance. Through coordinated action across human, animal, and environmental sectors, it can strengthen India's resilience against zoonotic diseases, antimicrobial resistance, and future pandemics while promoting ecological security.

Q4. WHAT MAKES IT 'EXAM-READY'?

- **GS-III-Aligned Structure:** Covers all major syllabus themes including IT, Biotechnology, Space, Health, Nanotechnology, Robotics, Nuclear Energy, and Emerging Technologies.
- **Ready-to-Quote Examples:** BharatGen, Genome India Project, NISAR Mission, Gaganyaan, Biopharma SHAKTI, National Quantum Mission, and more.

Q5. WHAT'S THE LAST-MILE BENEFIT IN THE EXAM HALL?

When others are trying to recall scattered technological developments, your 150/250-word answers enriched with examples, keywords, contemporary developments, and analytical insights. This document is designed not merely for coverage but for retention, recall, and impactful answer writing under time pressure.

FINAL WORD

Treat this document as your answer bank. Use it to enrich your notes, simulate questions, and visualize answers in UPSC language. Remember—when scientific understanding meets contemporary relevance and analytical presentation, high marks follow.

"Science is the foundation of progress, and technology is the instrument through which nations transform potential into power."

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1. IT, COMPUTERS AND ROBOTICS

1.1. BHARAT GEN

Why in the News?

Ministry of Science & Technology launched 'Bharat Gen' at the BharatGen Summit.

About Bharat Gen

- **Bharat Gen** is **India's First Sovereign AI Initiative** to develop foundational AI models.
- It is a **Multimodal Large Language Model (LLM)** project focused on creating Generative AI systems that can generate high-quality **text and multimodal content** (audio and imagery) in various Indian languages.
- **Launched** as a **non-profit company** with funding from the **Department of Science and Technology.**
- **Implementing Agency:** TIH Foundation for IOT and IOE (a **Section-8** company (not-for-profit) by IIT Bombay) under the National Mission on Interdisciplinary Cyber-Physical Systems (NM-ICPS).

Significance of BharatGen Programme

- **Support data sovereignty**: Trained on localized datasets (Bharat Data Sagar) to ensure models reflect Indian history, constitutional morality, and societal realities.
- **Digital & Language Inclusion:** Creation of Bharat-centric foundational LLM models focus on Indian languages, culture and tradition.
- **Sectoral Development**: It has released domain specific fine-tuned models for Ayurveda (Ayur Param), Indian agriculture (Agri Param) and Indian legal domain (Legal Param).
- **Startup Ecosystem and Innovation:** Empowering entrepreneurs with tools, mentorship, and collaboration to create innovative AI applications for India.
- **Skilling and Capacity Building:** Strengthen India's AI talent pool through fellowships, hackathons, and courses, **positioning it as a global innovation hub.**

About Generative AI and Large Language Models (LLMs)

- **Generative AI:** Generative AI is AI that can create original content—such as text, images, video, audio or software code—in response to a user's prompt or request.
  - **Generative AI tools** are built on underlying AI models, such as an **LLM,** which is the foundation for text-based generative AI tools like ChatGPT.
  - **Generative AI relies** on **deep learning models - algorithms** that simulate the learning and decision-making processes of the human brain.
- **LLMs:** LLMs are a category of **foundation models (large AI models)** capable of understanding and generating natural language and other types of content to perform a wide range of tasks.
  - **LLMs work** by learning patterns from vast amounts of data and becoming capable of recognizing and interpreting human language.
  - **LLMs** are typically based on a type of **neural network called transformer architecture** and consist of **multiple layers of neural networks** and self-attention mechanisms that enable them to learn patterns.

Conclusion

India futuristic approach aims to ensure inclusivity, diversity, and authentic Indian representation in the evolving landscape of emerging technologies. BharatGen is a visionary in the evolving tech landscape, empowering every citizen to engage with the digital world effortlessly.

1.1.1. SMALL LANGUAGE MODELS (SLMS)

Why in the News?

Union Minister for Electronics and IT stated that the future of AI will be shaped by Small Language Models (SLMs) rather than extremely Large Language Models (LLMs).

About Small Language Model (SLM)

- **Definition**: It is a compact AI system designed to process, understand, and generate natural language.
  - It has the same underlying architecture as **LLMs**—typically **neural networks** like **Transformers**.
- **SLMs** are compact models with millions to a few billion parameters and **less resource-hungry than LLMs.**
- **Key Examples**: Gemma and Gemini Nano **(Google), Llama** (smaller variants like Llama 3.2 1B and 3B by **Meta**), Microsoft's Phi series, Mistral 7B etc.
- **Techniques Used:** SLMs are created using techniques like **knowledge distillation** (where a small "student" model learns from a large "teacher" model), **pruning** (removing unnecessary parameters), and **quantization** (reducing precision to save memory).

Advantages of SLMs over LLMs

- **Efficiency and Speed**: SLMs require less computational power and memory. This allows them to process data faster (lower latency), making them ideal for real-time applications.
- **Cost-Effectiveness**: SLMs are cheaper to train, fine-tune, and run.
  - **E.g.,** Indian startups and **MSMEs** can deploy domain-specific SLMs.
- **Privacy and Security**: Since **SLMs** can run locally or in a private cloud/on-premise environment, data does not need to be sent to external servers, reducing the risk of data breaches.
- **Sustainability**: They consume **significantly less energy** than LLMs, reducing their carbon footprint.
- **Specialization (Task-Specific):** SLMs are best for specialized, industry-specific, or on-device tasks (e.g., coding, healthcare, legal analysis, or customer support).

Limitations of Small Language Models

- **Limited Capacity for Complex Reasoning:** SLMs generally struggle with tasks requiring multifaceted reasoning, intricate data patterns, or high levels of abstraction.
- **Reduced Generalization:** SLMs are often trained on smaller, more specialized datasets, which makes them **less flexible**.
- **Lower Accuracy on Long-Context Tasks:** SLMs often have a **smaller "context window"** (the amount of text they can retain and process at once).
- **Risk of Overfitting:** Due to their limited parameters, SLMs are more susceptible to overfitting during fine-tuning on small datasets, **often memorizing examples** instead of learning general patterns.
- **Hallucinations**: SLMs can sometimes generate incorrect or nonsensical information. Because they have a smaller knowledge base to cross-check facts.

Conclusion

India's AI strategy reflects a balanced and layered approach—focusing not only on advanced models but also on chips, infrastructure, and sustainable energy. By prioritizing Small Language Models alongside ecosystem development, India aims to deliver affordable, scalable, and inclusive AI solutions.

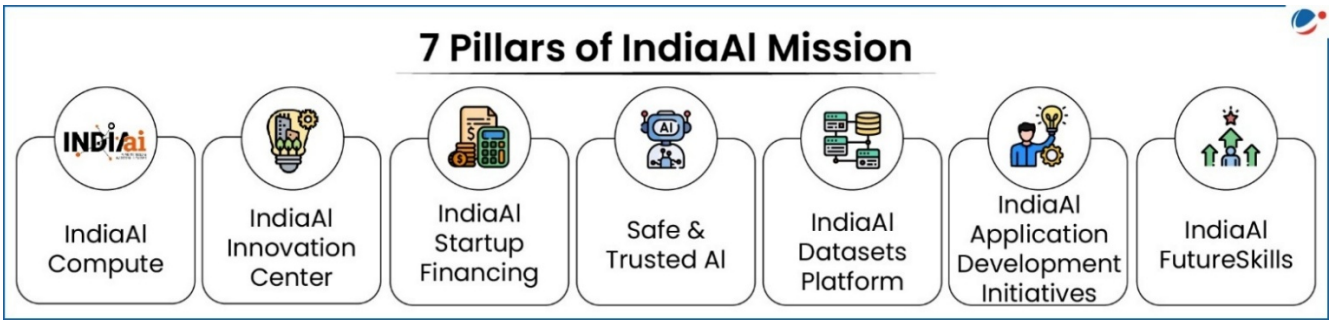
1.2. INDIAAI MISSION

Why in the news?

Parliamentary Standing Committee in its report analysed performance of IndiaAI Mission.

About IndiaAI Mission

- **Launch**: 2024 by Ministry of Electronics and Information Technology (MeitY).
- **Aim:** To foster AI innovation by democratizing computing access, enhancing data quality, and developing indigenous AI capabilities.
- **Implementing agency:** IndiaAI, under MeitY.



Issues & Recommendations of IndiaAI Mission

Key Issues	Recommendations
Under-utilization of Funds: Mission **utilized only 32%** of its Revised Estimate (RE) in **FY 2025-26** (as of Dec 2025).	**Financial Discipline:** Committee urged MeitY to strengthen **financial discipline**, **accelerate implementation** across all pillars.
Infrastructure Bottlenecks: Despite development of **GPUs clusters**, major issues exist like **high cost of hardware, global supply chain delays**.	**Stakeholder Consultation:** MeitY must conduct extensive stakeholder consultations to mitigate adversities related to hardware procurement and global supply constraints.
Environmental Impact: Establishing massive computing infrastructure involves **huge power and water consumption by data centres**.	**Environmental Mitigation:** MeitY should **consult environmentalists** to address ecological impact of setting up sovereign data centres.
R&D and Inclusivity Constraints: There are specific **challenges in developing a sovereign AI model.** Additionally, **AI research funding** remains largely **restricted to premier institutions** like IITs and national laboratories, limiting broader ecosystem growth.	**Broader R&D Evaluation:** MeitY needs to assess the real-life impact of new initiatives, such as the **Anusandhan National Research Foundation** and the Research Development and Innovation Fund, to **democratize research.**

Other Key Initiatives launched to Promote AI

- **National Strategy for Artificial Intelligence (AI for All)**: Launched by NITI Aayog in 2018.
- **National AI Portal (INDIAai):** A joint venture by MeitY, National e-Governance Division **(NeGD) and NASSCOM.**
- **AI Research Analytics and Knowledge Dissemination Platform (AIRAWAT):** provides a common compute platform for AI research.
- **National AI Skilling Program:** Enhancing AI skills through customized training modules with industry leaders.
- **Other**:
  - India's first agentic AI, Kruti, launched by Krutrim, can book cabs, pay bills, and perform other tasks.
  - **Bhashini Initiative**, AI-powered multilingual language platform under the National Language Translation Mission.

Conclusion

IndiaAI Mission will propel innovation and build domestic capacities to ensure the tech sovereignty of India. It will also create **highly skilled employment opportunities** to harness the demographic dividend of the country. IndiaAI Mission will help India demonstrate to the world how this **transformative technology** can be used for social good and enhance its global competitiveness.

1.3. ARTIFICIAL INTELLIGENCE AND HEALTHCARE AT A GLANCE

AI and Health Care

- **AI is revolutionizing healthcare by enhancing diagnosis, treatment, and patient monitoring, leading to more accurate results and personalized care.**

Applications of AI in HealthCare Sector

Robotic surgeries: E.g., Da Vinci robot (AIIMS, Delhi) performs complex procedures with precision.	**Clinical research and discovery:** E.g., ProteinSGM, a Generative AI model used for protein designing.	**Disease Management and Diagnostics:** E.g., MadhuNetrAI for diabetes retinal screening; iOncology.ai (AI platform developed helps in early detection of cancer.	**Electronic Health Records:** Tools like Eka Doc and Sunoh.Ai use AI and Natural Language Processing (NLP) to summarize patient records.	**Public Health Surveillance and Nutrition:** E.g., Media Disease Surveillance (MDS) is an early warnings based on AI scans national digital news sources for symptom clusters.

Initiatives taken to promote AI in healthcare sector

AI based Health Care Start-ups: E.g., AI based healthcare start-up, Wadhwani AI is developing various interventions related to the TB patient care.	**Ayushman Bharat Digital Mission (ABDM):** E.g., Leverages AI to enhance healthcare delivery and efficiency in India.	**Ethical Guidelines:** These are released by ICMR for Application of AI in Biomedical Research and Healthcare.	**Ayurgenomics & Ayush Grid** E.g., It uses AI to identify disease markers based on Prakriti (constitution types) and ancient texts.	**National Health Stack (NHS):** It includes National Health Analytics Platform.

Challenges related to AI in Healthcare

Algorithmic Bias: E.g., predictive models inaccurately assessed Black patients' health needs which used cost as a proxy for healthcare needs.	**Misinformation and Dehumanization:** AI errors or overreliance can spread misinformation and reduce meaningful patient-provider interactions.	**Representation bias:** It is present when samples from urban, wealthy, or connected groups lead to the ignoring of samples from rural, indigenous, or disenfranchised groups.	**Interoperability:** Diverse healthcare technologies and limited standardization hinder AI integration and raise risks of unauthorized data access.

Measures required to integrate AI in Healthcare

Enhance Doctor-AI Collaboration: Include AI in medical curriculum and promote interdisciplinary research.	**Promote Affordable and Scalable AI Solutions:** Scale up initiatives like Qure.ai, Niramai, eSanjeevani across India.	**Embrace regulatory sandboxes approach:** US, Canada, Japan, and Indonesia leverage regulatory sandboxes to foster innovation and pilot AI-driven digital health solutions.	**Use 'Human in The Loop' model of AI technology:** It gives room for humans to oversight the functioning and performance of the system.	**Global learning:** Finland uses AI-enabled wearables to monitor chronic patients in real-time, reducing hospital visits.

1.4. ARTIFICIAL INTELLIGENCE AND AGRICULTURE AT A GLANCE

AI and Agriculture

The application of AI in agriculture has been widely considered as one of the most viable solutions to address food inadequacy and to adapt to the need of a growing population.

Applications of AI in Agriculture Sector

Pest Management: AI-based pest surveillance systems, like the **National Pest Surveillance System** aids farmers for healthy harvest.

Agritech and Data Management: "Saagu Baagu" project under **AI4AI** has enhanced yields and incomes for **7,000 Chilli** farmers from Telangana, doubling their earnings.

Soil Health: Startups like **Fasal** and **CropIn** have developed systems that reduces input costs by up to **20%** while improving yields through balanced nutrition.

Precision and Smart Farming: E.g., **Bharat VISTAAR** (Virtually Integrated System to Access Agricultural Resources), an AI tool for agricultural information and advisory services.

Initiatives taken to promote AI in Agriculture

National Strategy for Artificial Intelligence: Launched by **NITI Aayog**,it emphasize on implementing AI in agriculture.

AI for Agriculture Innovation (AI4AI) initiative: **AI4AI** launched by the **World Economic Forum.**

Advisory and Decision Support Services: **Kisan-eMitra**, an AI Chatbot for the Pradhan Mantri Kisan Samman Nidhi **(PM-KISAN)** Scheme

Crop Insurance: **YES-TECH** (Yield Estimation System based on Technology); **CROPIC** (Collection of Real-Time Observations and Photographs of Crops).

National e-Governance Plan in Agriculture (NeGPA): Promoting the use of modern technologies like **AI, Machine Learning,** and **Data Analytics.**

Challenges in implementing AI in agriculture

Accuracy: Missing data in parameters like soil health, local micro-climates, or pesticide usage.

High Cost of AI Technology: The initial investment for AI-enabled hardware compatible smart machinery is prohibitively high.

Low Digital Literacy among Farmers: Many farmers are unfamiliar with using digital apps or interpreting AI-driven advisories.

Fragmented Landholdings: Indian farmer's average landholding is just **1.08 hectares**, makes it difficult to implement uniform AI solutions like automated irrigation or robotic weed control.

Way forward to implement AI in agriculture

Promote Farmer Awareness: Use **Krishi Vigyan Kendras (KVKs)** and extension services to introduce AI tools

Encourage Localized and Language-Friendly AI Solutions: Promote voice-assisted and low-tech AI interfaces for smallholder farmers.

Integrate AI in research and development (R&D): R&D within institutions like **ICAR** and state agriculture universities.

1.5. QUANTUM TECHNOLOGY AT A GLANCE

Quantum Technology

Definition: Quantum technology is a class of technology that works by using the principles of quantum mechanics (the physics of sub-atomic particles), including quantum superposition and quantum entanglement.

Superposition: Unlike classical bits (which are either 0 or 1), quantum bits (qubits) can exist in a state of 0, 1, or both simultaneously.

Entanglement: A phenomenon where two particles become linked; a change in the state of one instantly affects the other, regardless of distance.

Status in India of Quantum Technology: India ranks **2nd** globally in the number of graduates in quantum-relevant fields (approximately **91,000**), behind only the EU.

Application of Quantum Technology

Simulations: E.g. In Health care & well-being (advancing medical imaging and diagnosis) and Quantum chemistry (developing new vaccines and drugs).

Communications: Includes Quantum key distribution (QKD is a secure communication method for exchanging encryption keys only known between shared parties.)

Material & Devices: Design and synthesis of Quantum Chips (E.g. Google's quantum chip Willow), etc.

Quantum Sensing & Metrology: E.g., Quantum Radar and Imaging can detect stealth aircraft and submarines invisible to traditional radar.

Quantum AI: Enables advanced AI models by accessing training data beyond classical computer capabilities.

Initiatives taken to promote Quantum Technology

QuEST (Quantum Enabled Science and Technology): Launched in **2018** to fund national quantum labs and build foundational infrastructure.

Quantum Computing Applications Lab (QCAL): To accelerate quantum computing-led research.

Quantum Frontier mission of Prime Minister's Science, Technology, and Innovation Advisory Council (PM-STIAC).

Critical and Emergency Technology Working Group: In **2021**, the QUAD leaders established it to ensure that the standards and frameworks for key technologies such as Quantum Computing

Concerns related to Quantum Technology

Error correction: Superposition produces many possible outcomes, and measurement may give a random result; therefore, error-correction is ongoing areas of active research.

Fragility of Qubits: Quantum states are highly susceptible to "noise" and environmental disturbances, leading to decoherence.

Harvest Now, Decrypt Later (HNDL) attacks, involve storing encrypted data now to decrypt it in the future using quantum computers.

Hardware Requirements: Building Quantum systems requires extreme isolation and ultracold temperatures near absolute zero.

Measures required to promote Quantum Technology

Create Regulatory Body: Set up a central authority to govern quantum technology.

Facilitate technology transfer: Bridge the academia-industry gap by enabling private firms to commercialize cutting-edge quantum technologies.

Global collaboration: E.g., With World Economic Forum's Quantum Economy Network which aims to raise awareness and understanding of quantum technology

Strengthen IPR Framework: Ensure clear rules for IP ownership, licensing, and transfer.

1.5.1. NATIONAL QUANTUM MISSION

Why in news?

Under the National Quantum Mission, the foundation stone of the **Quantum Valley project** was recently laid in Amaravati, Andhra Pradesh**.**

More on the news

- The Project seeks to make Amravati a global hub for quantum technologies and to install **India's first 133-qubit quantum computer by 2026**.
- It is an example of a **'Triple Helix Model'** involving a tripartite alliance between the Government, industry leaders (IBM, TCS, L&T), and academia.

National Quantum Mission

- **About:** It is a flagship initiative launched by the Government of India **for period of 2023-2031** with an aim to make India a global leader in **quantum technologies.**
- **Mission objectives:**
  - **Quantum Computing Evolution:** Develop intermediate-scale quantum computers with 20-50 physical qubits (3 years), 50-100 physical qubits (5 years), and 50-1000 physical qubits (8 years) across platforms.
  - **Satellite-Based Quantum Communication**: Establish satellite-enabled quantum-secured communication between two ground stations over 2000 km within India.
  - **Advanced Quantum Sensing & Clocks:** Design highly sensitive quantum devices including magnetometers with 1 femto-Tesla/sqrt (Hz) sensitivity in atomic systems
  - **Quantum Materials & Devices:** Develop and synthesize next-generation quantum materials such as superconductors, novel semiconductor structures, and topological materials for the fabrication of qubits.
- **Governance:** Under the **Ministry of Science and Technology**; it is one of the 9 missions governed by the **PM-STIAC**.
- **Implementation Strategy: Thematic Hubs:** The mission established 4 specialized hubs (IISc Bengaluru, IIT Madras, IIT Bombay, IIT Delhi) at leading institutions following the **Hub-Spoke-Spike model.**

Conclusion

India aims to be among the top three quantum economies by 2035. To achieve this, we should focus on greater collaborations, capacity building and larger R&D share towards quantum technologies.

1.5.2. NOBEL PRIZE IN PHYSICS 2025

Why in the News?

John Clarke, Michel H. Devoret and John M. Martinis have been awarded **Nobel Prize in Physics** for the discovery of macroscopic quantum mechanical tunnelling and energy quantisation in an electric circuit.

Background

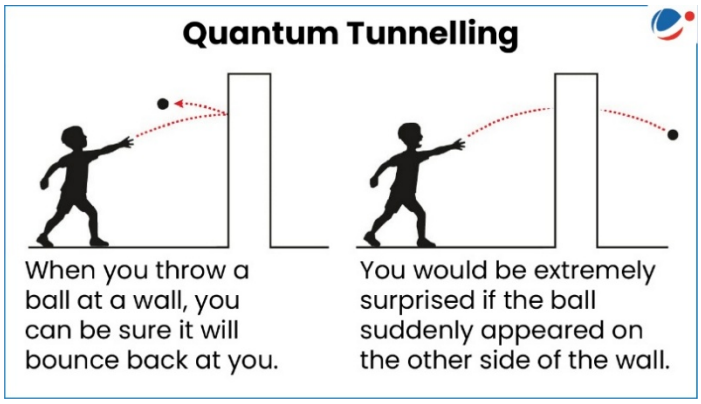
- The quantum effect is prominent at the microscopic level, **vanish at the macroscopic scale** (e.g., in everyday objects like a cricket ball).
- The **2025 Nobel Prize** honors experiments that demonstrated how **quantum phenomena**—such as **quantum tunnelling**—can also be **observed in macroscopic systems**.

Quantisation of Energy

- At the microscopic level, particles **absorb and emit energy in discrete packets**, known as **quanta**.
- Particles such as **atoms, electrons, and protons** can exist only in certain **fixed energy levels**, and not in between.
- This phenomenon is known as the **quantisation of energy**.

Quantum Tunnelling

- **Quantum physics** reveals a surprising phenomenon: when a **particle encounters a barrier** (a wall of potential energy), there exists a **finite probability** that it may **pass through the barrier** and appear on the other side.
- This strange behavior, known as **quantum tunnelling**, occurred only at the **microscopic scale**.
- A classic example is **radioactive decay**, where part of an atomic nucleus escapes by tunnelling through its potential barrier — as seen in **alpha decay**.


Quantum Tunnelling
When you throw a ball at a wall, you can be sure it will bounce back at you.
You would be extremely surprised if the ball suddenly appeared on the other side of the wall.

About the Experiment and Result

- John Clarke, Michel Devoret, and John Martinis built an electric circuit using two superconductors separated by an insulator — a **Josephson Junction**.
- They demonstrated that all charged particles in the circuit behaved collectively as a **single quantum particle.**
- They also **demonstrated the quantization of energy in the circuit.**

Significance of the discovery

- **The discovery revealed a macroscopic quantum state**, enabling experiments that apply quantum phenomena to large-scale systems.
- **The Josephson Junction acts** as an artificial atom, allowing researchers to simulate and study complex quantum systems.
- This principle was later used to **create quantum bits (qubits)**.
- **The work has advanced both practical quantum technologies** such as quantum computing, quantum cryptography and quantum sensors and the theoretical understanding of quantum physics.

Conclusion

Even after a century since its discovery, the quantum world surprises with its bizarre but fascinating behaviour. The theory which is fundamental for understanding the behaviour of nature at minute scale is also becoming the foundation of many modern technologies.

1.6. SUPERCOMPUTER

Why in the News?

Ministry of Electronics and Information Technology (MeitY) launched 'Param Shakti' at Indian Institute of Technology Madras.

About Param Shakti

- It is an indigenously developed and manufactured **3.1 Petaflop supercomputing system**.
- The project has been funded under the **National Supercomputing Mission (NSM)**
- It is built using **Centre for Development of Advanced Computing (C-DAC)'s RUDRA** series of servers and runs on an **open-source** software stack, including **AlmaLinux.**

What is a Supercomputer?

- It is a **high-performance computing system** that delivers exceptional processing power and computational capacity.
- **Performance** is measured in **floating-point operations per second (FLOPS**) instead of million instruction per second (MIPS) used for regular computers.

Applications of Supercomputers

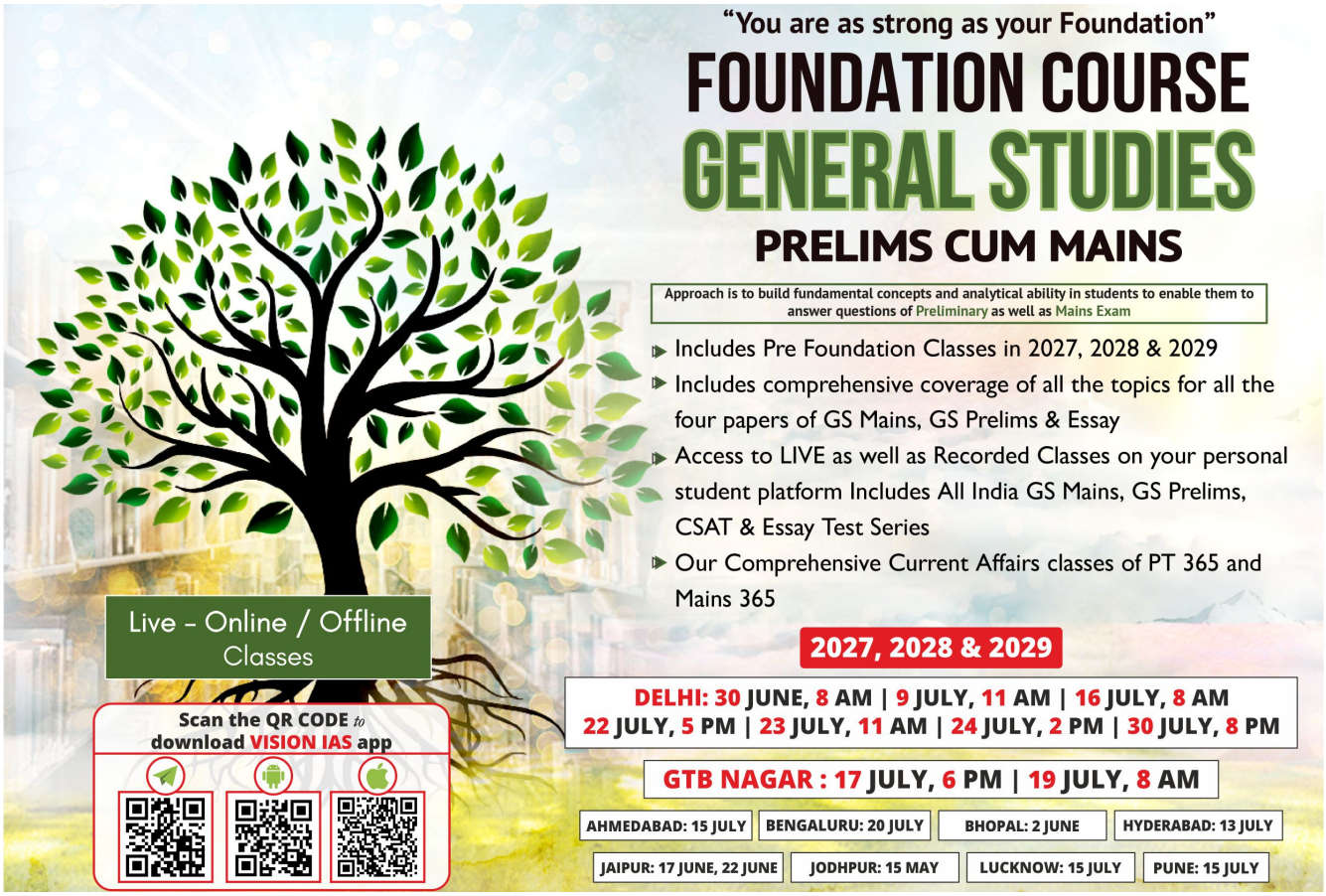
- **Cutting Edge Research**: Param Pravega supercomputer caters to quantum mechanics.
- **Governance**: Use of AIRAWAT system for language model development for Digital India BHASHINI program.
- **Weather forecasting:** 'Pratyush' supercomputer is dedicated to weather and climate research
- **Internal Security**: AIRAWAT-PSAI was leveraged by C-DOT to identify issuance of benami SIM cards.
- **Health and Medicine:** PARAM Shakti facilitated extensive screening of various cancer specific receptors, aerospace engineering, materials science, climate modelling, drug discovery, and advanced manufacturing etc.
- **Disaster Management:** PARAM Ganga was utilized for a study on cloud bursts in Uttarakhand.

About National Supercomputing Mission (NSM)

- **Launched**: 2015
- **Objective**: To connect national academic and R&D (research and development) institutions with a grid of over **70 high-performance** computing facilities.
- The supercomputers are networked on the National Supercomputing grid over the **National Knowledge Network (NKN)**.
- **NSM** is steered jointly by the Department of Science and Technology (DST) and MeitY.
- **Implemented** by Centre for Development of Advanced Computing (C-DAC), Pune, and the Indian Institute of Science (IISc), Bengaluru.

Conclusion

The National Supercomputing Mission strengthens India's global supercomputing position by promoting indigenous development and innovation. With sustained investment, India is set to become a global leader in High-Performance Computing.


"You are as strong as your Foundation"
FOUNDATION COURSE
GENERAL STUDIES
PRELIMS CUM MAINS
Approach is to build fundamental concepts and analytical ability in students to enable them to answer questions of Preliminary as well as Mains Exam
Includes Pre Foundation Classes in 2027, 2028 & 2029
Includes comprehensive coverage of all the topics for all the four papers of GS Mains, GS Prelims & Essay
Access to LIVE as well as Recorded Classes on your personal student platform Includes All India GS Mains, GS Prelims, CSAT & Essay Test Series
Our Comprehensive Current Affairs classes of PT 365 and Mains 365
Live - Online / Offline Classes
2027, 2028 & 2029
DELHI: 30 JUNE, 8 AM | 9 JULY, 11 AM | 16 JULY, 8 AM
22 JULY, 5 PM | 23 JULY, 11 AM | 24 JULY, 2 PM | 30 JULY, 8 PM
GTB NAGAR : 17 JULY, 6 PM | 19 JULY, 8 AM
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JODHPUR: 15 MAY
LUCKNOW: 15 JULY
PUNE: 15 JULY

1.7. BLOCKCHAIN TECHNOLOGY AT A GLANCE

Blockchain Technology

Definition: Blockchain is a **decentralized, distributed ledger** technology that ensures **tamper-proof, transparent,** and **auditable** record-keeping.

Working Mechanism: It is an exchange process, which works on **data blocks.** In this, **one block is connected to another block.** Transactions are **validated and verified** through **consensus protocols** across **nodes** of the **Blockchain network.**

Applications of Blockchain Technology

Cryptocurrencies: E.g., Bitcoin, Ethereum offer features like **Decentralization, limited supply, borderless transaction.**

Supply Chain Management: E.g., Coffee Board of India uses blockchain to trace coffee production.

Voting Systems: E.g., India has developed a Remote voting system that enables encrypted vote for migrant voters.

Intellectual Property Protection: E.g., Project Resonance in collaboration with WIPO uses Blockchain to protect music IP rights.

Logistics: E.g., Karnataka's Aushada system tracks medicine movement from manufacturer to hospitals, including quality checks.

Property: E.g., 'Blockchain-powered Property Management System' records all property transactions verifying ownership, rights, and liabilities, reducing litigation. and speeding dispute resolution.

Initiatives taken to develop and promote blockchain technology

National Strategy on Blockchain (2021): To create trusted digital platforms through shared Blockchain infrastructure.

Future Skills PRIME: For upskilling in Blockchain.

Ethical Blockchain Governance: World Economic Forum's Presidio Principles for designing blockchain applications.

Centre of Excellence in Blockchain Technology (CoE): Established to offer blockchain-as-a-service (BaaS) infrastructure for government departments.

National Blockchain Infrastructure: Vishvasya or National Blockchain Technology Stack which offers Blockchain-as-a-Service (BaaS) and is part of the broader National Blockchain Framework (NBF).

Challenges related to Blockchain Technology

Non-Interoperability: Different blockchain platforms are often incompatible with each other.

Storage: Demands heavy storage as data stored is replicated at all the nodes and becomes perpetual.

Energy Consumption: Some blockchain models (like Proof-of-Work) consume excessive electricity and computing power. It further escalates with need for the systems to be kept cool to function.

Lack of Skilled Workforce: Despite initiatives like Kerala Blockchain Academy, demand far exceeds the supply of talent.

Way forward to further streamlining Blockchain

National Level Blockchain Framework (NLBF): For scaling, deployments for developed applications, creating shared infrastructure, etc.

Create Regulatory Sandboxes: Allow controlled testing of blockchain solutions before large-scale deployment.

Expand Use Cases Beyond Cryptocurrency: E.g., Maharashtra State Blockchain Sandbox for land records and agriculture.

Promote Green Blockchain Solutions: Encourage energy-efficient consensus mechanisms such as Proof-of-Stake (PoS).

1.7.1. STABLECOINS

Why in the News?

As per a new IMF paper, stablecoins may accelerate currency substitution, weaken central bank control.

About Stablecoins

- These are **crypto assets** designed to maintain a stable value relative to a **specific peg** (e.g. Fiat currency), distinguishing them from **volatile unbacked crypto** assets like Bitcoin.
- **Issuers:** Generally issued and operated in a centralized manner by entities such as crypto firms or financial institutions.
- The **adoption of stablecoins** is leading to a new three-layered financial structure:
  - **Blockchain base layer**: Decentralized and auditable infrastructure.
  - **Reserve layer:** Regulated institutions backing stablecoins with transparent reserves.
  - **Interface layer:** Payment cards, APIs, and digital wallets facilitating everyday commerce.

Risks associated with stablecoins

- **Run Risk:** If users lose confidence, mass redemptions can trigger fire sales of reserve assets (such as US Treasury bills), potentially impairing broader market functioning.
- **Currency Substitution:** Widespread adoption of foreign-denominated stablecoins in countries with high inflation/weak institutions could undermine monetary sovereignty and weaken effectiveness of domestic monetary policy.
- **Banking Disintermediation:** They might reduce banks' stable funding sources, potentially impacting lending capabilities.
- **Financial Integrity:** The pseudonymity of blockchain transactions creates risks for money laundering and terrorism financing.

Way Forward

- **Promoting Central Bank Digital Currencies (CBDCs**): CBDCs operate within a regulated framework, ensuring consumer protection, etc. unlike many stablecoins which lack regulatory oversight.
  - **CBDCs** is a **legal tender** and a central bank **liability in digital form denominated in sovereign currency** and appearing on central bank balance sheet.
- **Develop Macrofinancial Safeguards:** For issues like currency substitution, volatile capital flows, and payments fragmentation.
- **Strengthening International Cooperation & Harmonizing Regulatory Implementation across globe:** Fragmentation in regulation could lead to arbitrage, where issuers move to jurisdictions with weaker oversight.

Conclusion

India's existing digital infrastructure, including UPI and Aadhaar, positions it uniquely for leveraging stablecoins to enhance financial inclusion and interoperability. Stablecoins are not about replacing fiat but redefining its role in a digitally operated economy. As nations increasingly embrace stable, programmable, and globally interoperable currency systems, they will play a pivotal role in shaping the future digital economy.

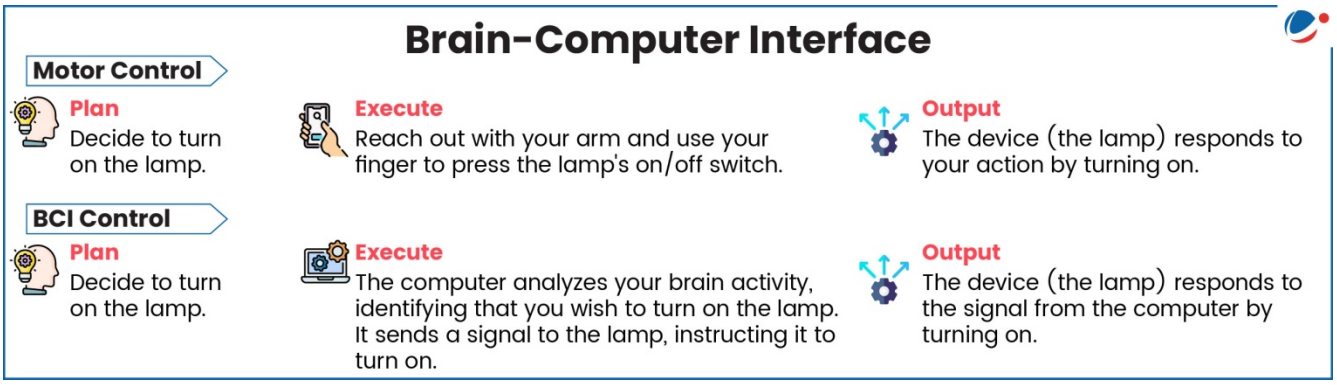
1.8. BRAIN-COMPUTER INTERFACE (BCI)

Why in the News?

Stanford scientists have created password-protected mind reading Brain-Computer Interface (BCI).

What is a Brain-Computer Interface?

- A BCI enables **direct brain-to-device communication**, translating neural signals into commands.
  - This **bypasses muscular control**, allowing users to operate applications with thought alone.
- BCIs **acquire brain activity (via invasive implants or non-invasive wearables)**, process signals, and send commands, with **feedback crucial for user adaptation.**


Brain-Computer Interface
Motor Control
Plan
Decide to turn on the lamp.
Execute
Reach out with your arm and use your finger to press the lamp's on/off switch.
Output
The device (the lamp) responds to your action by turning on.
BCI Control
Plan
Decide to turn on the lamp.
Execute
The computer analyzes your brain activity, identifying that you wish to turn on the lamp. It sends a signal to the lamp, instructing it to turn on.
Output
The device (the lamp) responds to the signal from the computer by turning on.

Key Applications of BCIs

- **Medical:** Restoring mobility and speech for patients with paralysis, ALS, or stroke.
- **Mental Wellness:** Providing feedback for mental health management.
- **Gaming/Industry:** Enabling immersive gaming and decision support systems.
- **Cognitive Enhancement:** Potential for enhancing memory, attention, and decision making.

Key Concerns Related to BCIs

- **Cybersecurity:** Risks like brain tapping (intercepting private thoughts/beliefs), misleading stimuli attacks (mind control), and adversarial attacks on AI components.
- **Privacy:** Protecting sensitive neural data from unauthorized access.
- **Cognitive Liberty:** Threat to an individual's mental self-determination.
- **Health Impacts:** Unclear long-term consequences of BCI use.
- **Regulatory & Cost:** Lack of standardized regulations and high costs limit accessibility.

Way Forward

- **Robust Regulations:** Implementing tailored data privacy laws, ensuring transparency and informed consent.
- **Enhanced Security:** Developing BCI-specific access controls and defense strategies.
- **Establishing neurorights:** To **safeguard mental privacy**, cognitive autonomy, and freedom of thought of individuals **from exploitation and unauthorized interference.**

Related News

Moonshot Project

- **IISc and Pratiksha Trust** launched Moonshot project on Brain Co-processors.
  - The project aims to develop both **implantable and non-invasive brain co-processors** capable of **decoding neural activity** from brain recordings, processing and **re-encoding the signals** back into the brain using **neural stimulation**.
- **About Brain Co-processors**
  - They are **AI-powered**, **bidirectional** neural interfaces that decode, analyze, and re-encode brain signals.
  - **Unlike** conventional **BCIs** (Brain-Computer Interface), **they target the full cognitive loop** i.e., perception, attention, decision-making, and motor control.
  - **Primary goal:** Restore reach and grasp in stroke survivors.

1.9. 3D PRINTING TECHNOLOGY AT A GLANCE

3D Printing Technology

3D printing, or additive manufacturing, is a process of creating three-dimensional objects from a digital file by adding material layer by layer until the final form is achieved.

Applications of 3-D Printing

Aerospace:	Automotive:	Construction:	Healthcare:	Consumer Goods:
E.g., Agnikul Cosmos has successfully launched world's first single-piece 3D printed rocket engine SOrTeD.	E.g., The Mahindra Group has integrated AM into its design process, streamlining prototype development.	E.g., 'Amaze 28', Kerala's first 3D printed building at PTP Nagar KESNIK campus, was constructed in 28 days.	E.g., Osteo3D, based in Bangalore, has led 3D printing medical models and surgical guides.	E.g., Tanishq is making complex designs with 3D printing.

Initiatives taken to promote 3-D printing

National Strategy for Additive Manufacturing, 2022: Launched by **MeitY** Aspires to achieve 5% of Global AM market share and add nearly **US$ 1Bn** to the GDP by 2025.	**National Institute of Electronics & Information Technology, Aurangabad:** It has established a 3D printing lab.
Public Infrastructure Innovation: India's first 3D-printed post office was created in Bengaluru.	**Centre of Excellence in Additive Manufacturing (AM):** It is established by **IISc** for high-performance metallic alloys.

Challenges of 3-D printing

Expensive:	Limited Materials:	Import Dependency:	Restricted Build Size:	Limitations in design:
Initial investment in equipment is substantial.	Selection of plastics and metals is not exhaustive.	India depends heavily on imported 3D printers and raw materials.	Print chambers have small sizes; larger parts need to be joined after printing.	Layers can delaminate under stress due to the layer-by-layer production process.

Way forward to improve 3-D printing

Develop Indigenous 3D Printing Materials: Reduce dependence on imported polymers, resins, and metal powders.	**Create Robust Standards and Certification Frameworks:** E.g., Standardization of 3D-printed medical implants to ensure patient safety.
Enhance Skill Development: Introduce additive manufacturing courses in engineering institutions and Industrial Training Institutes (ITIs).	**Promote Sustainable Practices** E.g., use of biodegradable or recyclable materials and energy-efficient printing processes to make 3D printing

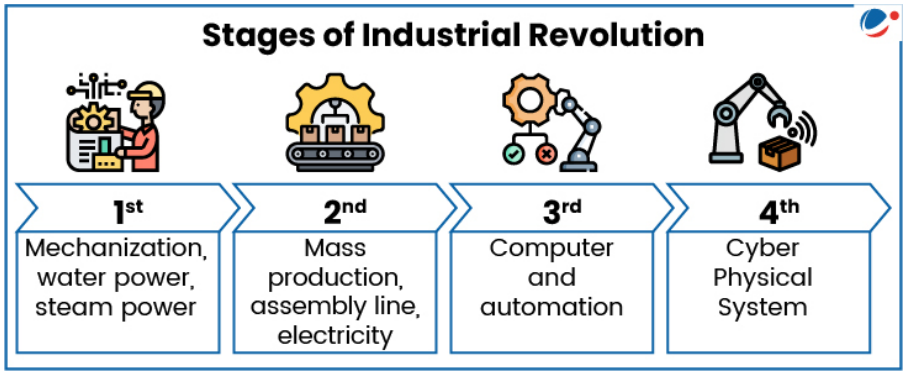
1.10. FOURTH INDUSTRIAL REVOLUTION

Why in the News?

WEF announced five new 'Fourth Industrial Revolution (IR 4.0) Centre globally. One of the Centre will be built in in **Andhra Pradesh**, **India**. It will be 3rd such centre in India **after Mumbai and Telangana**.

What is the Fourth Industrial Revolution?

- The term was coined by **Klaus Schwab,** founder of the World Economic Forum (WEF).
- **IR 4.0** describes the **current era in which digital, physical** and **biological technologies converge** such as AI, robotics, the Internet of Things (IoT), etc.
- Unlike earlier revolutions, IR 4.0 is **blurring boundaries between physical, digital** and **biological systems.**



Significance of Fourth Industrial Revolution

- **Economic growth:** Enhances productivity and improves **supply chain resilience** through automation, data analytics and smart manufacturing.
- **Inclusive development potential:** Offers **developing countries** like **India an opportunity to leapfrog** legacy technologies and expand digital access.
- **Environmental sustainability:** Supports **low-carbon and resource-efficient growth** through smart grids, precision agriculture and circular economy practices.
  - E.g., **"Lighthouse" factories** have demonstrated significant reductions in CO_2 emissions and water usage through predictive analytics and IoT.
- **Human capital centrality:** Shifts the focus from physical labour to skills, innovation, and lifelong learning.

Challenges and Risks

- **The Technology Gap:** There is a risk of **widening inequality between developed and developing nations.**
  - **E.g.,** Ten "frontrunner" economies account for **91% of global patent applications** in advanced digital production technologies.
- **Workforce Disruption:** Almost 40 % of global employment is exposed to AI (IMF).
- **Security and Cyber Resilience:** As industrial sites become more connected, they become **vulnerable to cyberattacks, espionage,** and **disruption of critical infrastructure**.
- **Environmental Effects:** The increased use of sensors, data centers, and connected devices **consumes energy and scarce resources**.

Conclusion

The Fourth Industrial Revolution is about more than technology-driven change. It is an opportunity to help everyone create an inclusive, human-centered future. However exponential and disruptive nature of technology demands long-term decision making to ensure that they are governed in a way that maximizes societal benefit whilst minimizing potential misuse or harm.

1.11. DIGITAL TWIN INITIATIVE

Why in the News?

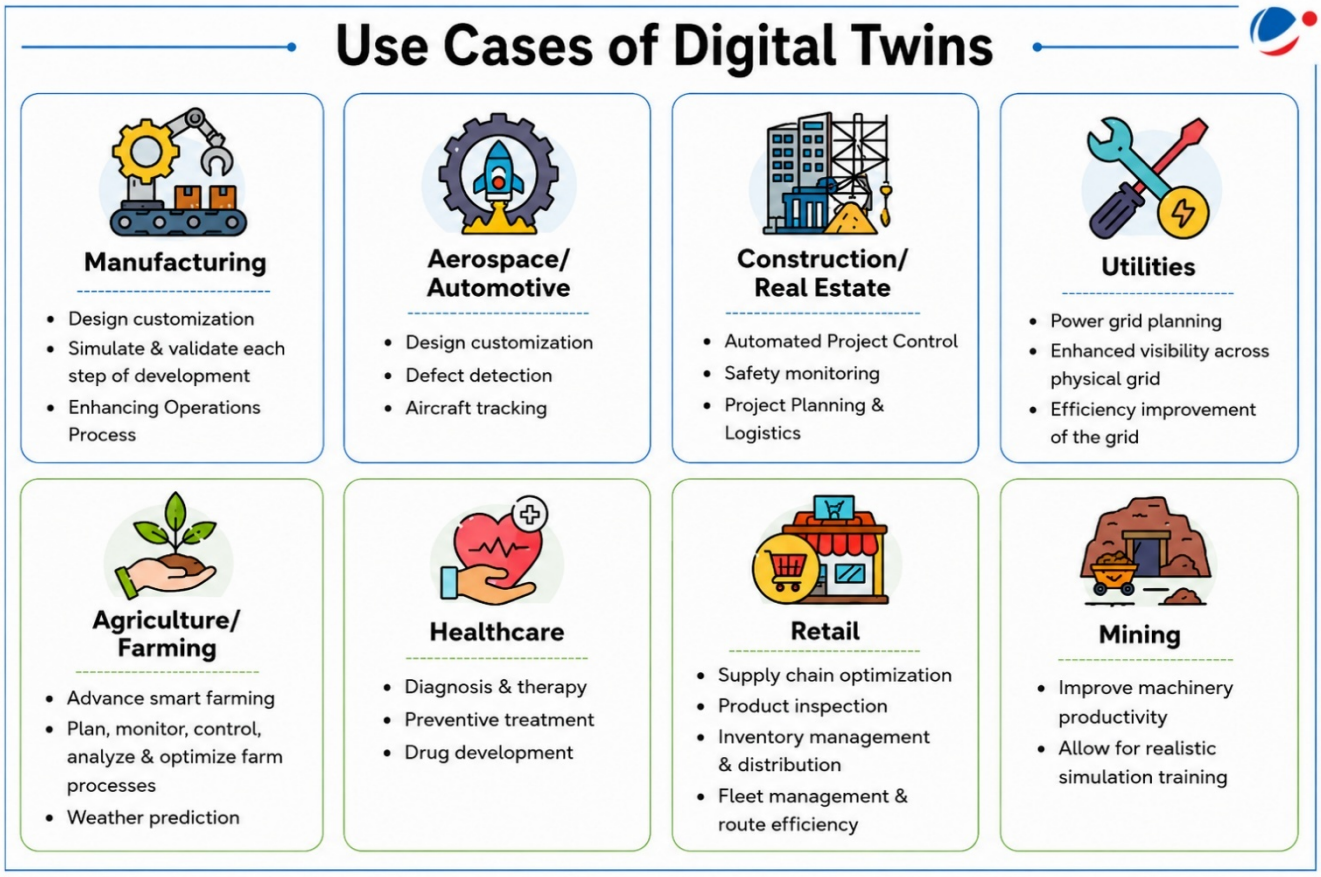
V.O. Chidambaranar Port Authority in Tamil Nadu became the first port in India to launch Digital Twin initiative.

About Digital Twin Initiative

- **Digital Twin** is a **virtual representation** of a physical object or system that uses real-time data to accurately reflect its real-world counterpart's behavior, performance and conditions.
  - It enables **continuous monitoring, simulation and analysis** of an object, product or system over the course of its lifecycle, **from design and production to maintenance and decommissioning**.
- **Digital Twin for Port Management:** It will create a **real-time virtual replica** of the port's infrastructure, operational assets, and maritime ecosystem.
  - **Technologies:** The platform will use IoT sensors, GPS tracking, LiDAR mapping, CCTV networks, etc.

Significance of Digital twins

- **Remote monitoring** makes it viable for usage in hazardous operations
- **Better predictions** helping in policy decisions
- **Improvement in operational efficiency** thereby maintaining the output quality
- **Aid in Urban planning** by creating different simulations and forecasting.



Conclusion

A digital twin initiative isn't just a tech project—it's a business transformation strategy. Organizations that implement it well gain a powerful ability to predict, simulate, and optimize before making real-world changes.

1.12. KEY WORDS

Keywords			
Bharat Gen	**Supercomputer**	**Stablecoins**	**Small Language Model (SLM)**
3D Printing	**Digital Twin**	**Fourth Industrial Revolution**	**Brain-Computer Interface**
Robotics technology	**Blockchain Technology**	**Bharat VISTAAR**	**IndiaAI Mission**

1.13. PRACTICE QUESTION

Quantum technologies are expected to drive the next industrial revolution. Discuss their significance for India and the challenges in building a robust quantum ecosystem.			
Introduction	**Body Part 1**	**Body Part 2**	**Conclusion**
Briefly define Quantum Technology.	Significance of Quantum Technologies for India.	Challenges in Building a Robust Quantum Ecosystem.	Way forward + futuristic conclusion

2. BIOTECHNOLOGY AND NANOTECHNOLOGY

2.1. BIOTECHNOLOGY AT A GLANCE

Biotechnology

Organisation for Economic Co-operation and Development (OECD) defines biotechnology as "the application of science and technology to living organisms as well as parts, products and models thereof, to alter living or nonliving materials for the production of knowledge, goods and services.

Applications of Biotechnology

Molecular Diagnostics: PCR and ELISA techniques for rapid disease detection; over 1,000 gene tests identify genetic mutations.	**Health & Medicine:** E.g., DNA-based vaccines (ZyCoV-D for COVID-19) and cures for Hepatitis B.	**Agriculture:** Income rose by 40–50% through improved bio-fortified rice in Chhattisgarh.	**Tissue Engineering:** Lab-grown tissues and organs for transplantation; biocompatible implants.	**Therapeutics:** Produces recombinant insulin, erythropoietin for anemia, and monoclonal antibodies for cancer.

Initiatives taken to promote Biotechnology in India

Biotechnology for Economy, Environment and Employment Policy: Launched by DBT, for fostering High-Performance Biomanufacturing by adoption of cutting-edge advanced technologies.	**Biotechnology Ignition Grant (BIG):** Up to ₹50 lakh for 18 months to support early-stage startups.	**National Biopharma Mission (NBM):** For biopharmaceuticals, vaccines, biosimilars, medical devices, and diagnostics.	**National Speed Breeding Crop Facility:** Located at the National Agri-Food Biotechnology Institute (NABI) in Mohali.	**National Biotechnology Development Strategy (2021-25):** To make India globally competitive in biotechnology and be a USD 150 billion Bioeconomy by 2025.

Challenges/Concerns related to Biotechnology

Low R&D: Less than 1% of India's GDP.	**Intellectual Property Right regime:** Strict standards under Patents act 2005 and Compulsory licensing.	**Ethical Issues:** E.g., Bio piracy, Designer Babies, Human clinical trials.	**Biosafety and Biosecurity Risks:** Risks of accidental release of genetically modified organisms (GMOs), bioterrorism.	**Genomic Data Security:** Companies handling large genomic databases face the challenge of protecting data.

Way forward to promote Biotechnology

Launch programmes like i3c BRIC-RCB-PhD Program for building a skilled workforce.	Investing in AI tools for drug discovery as seen with startups like Elucidata (building an analytical platform for drug discovery teams).	Collaboration between government and industry for improving IP regime.	Extend and design PLI schemes specifically for the biotech sector, particularly for high-value biopharmaceuticals, diagnostics.	Encourage Bio-entrepreneurship Expand the BioNEST incubator network.

2.1.1. BIOECONOMY

Why in the News?

BioE3 (Biotechnology for Economy, Environment and Employment) Policy completed one year with bioeconomy-led growth and sector **projected to grow to $1 trillion by 2047.**

About BioE3 Policy

- **Aim:** Accelerating development of technologies for bio-based products and their commercialization by setting up of **BioEnablers (**Bio-Artificial Intelligence Hubs, Biofoundries, Biomanufacturing Hubs).
- **Implementation:** Department of Biotechnology (DBT), Ministry of Science and Technology.
- **6 thematic sectors**: Bio-based chemicals and enzymes, Functional foods and Smart proteins, Precision biotherapeutics, Climate resilient agriculture, Carbon capture and its utilization, Futuristic marine and space research.
- **Key achievements in 1 year**
  - Inauguration of **India's first Biomanufacturing Institute** at Mohali (Punjab).
  - **Launch of more than a dozen joint research calls** covering advanced areas like cell and gene therapy, climate-smart agriculture, carbon capture, and functional foods.
  - **DBT has** initiated **centre-state partnerships**, including an MoU with Assam to establish a BioE3 Cell.
  - India's first **National Biofoundry Network** to help scale up proof of concept launched.
  - **Biofoundry:** Automated facility that designs, builds, and optimizes engineered organisms by integrating DNA synthesis, gene editing, and high-throughput biomanufacturing workflows.

About Bioeconomy

- **Use of renewable biological resources** to produce food, energy and industrial goods, which supports sustainability and economic growth.
- **Key sectors:** BioPharma & BioMedical, BioAgr, BioIndustrial, BioResearch, etc
- **Status: India's** bioeconomy grew from **$10 billion (2014) to $195.3 billion (2025)**.

Significance of India's Bioeconomy

- **High-Value Sector:** The bioeconomy contributes roughly 4.8% to GDP (India Bioeconomy Report 2025).
- **Lower Current Account Deficit:** $13-14 billion savings in foreign exchange due to reduction in petrol imports.
- **Growth Drivers:** 20% blending of ethanol in petrol, usage of enzymes and microbes in industrial sectors like textiles, detergents, food processing, biofuels etc.
- **Research and Innovation:** E.g., India's first indigenously developed antibiotic (Nafithromycin), establishment of a National Biobank etc.

Conclusion

India is steadily moving towards its target of a USD 300 billion bioeconomy by 2030, supported by a strong base of scientists, entrepreneurs, and startups.

2.1.2. BIOPHARMA SHAKTI

Why in the News?

Union Budget 2026-27 announced Biopharma SHAKTI (Strategy for Healthcare Advancement through Knowledge, Technology & Innovation) scheme to position India as a Global Biomanufacturing Hub.

About Biopharma SHAKTI scheme

- **Objective:** Develop India into a global biopharmaceutical manufacturing hub by building the ecosystem for domestic production of biologics and biosimilars.
  - **Biologics** are a **class of medicines** (E.g., vaccines, somatic cells, gene therapy, etc.) that are made from natural and living sources like animal and plant cells, and microorganisms.

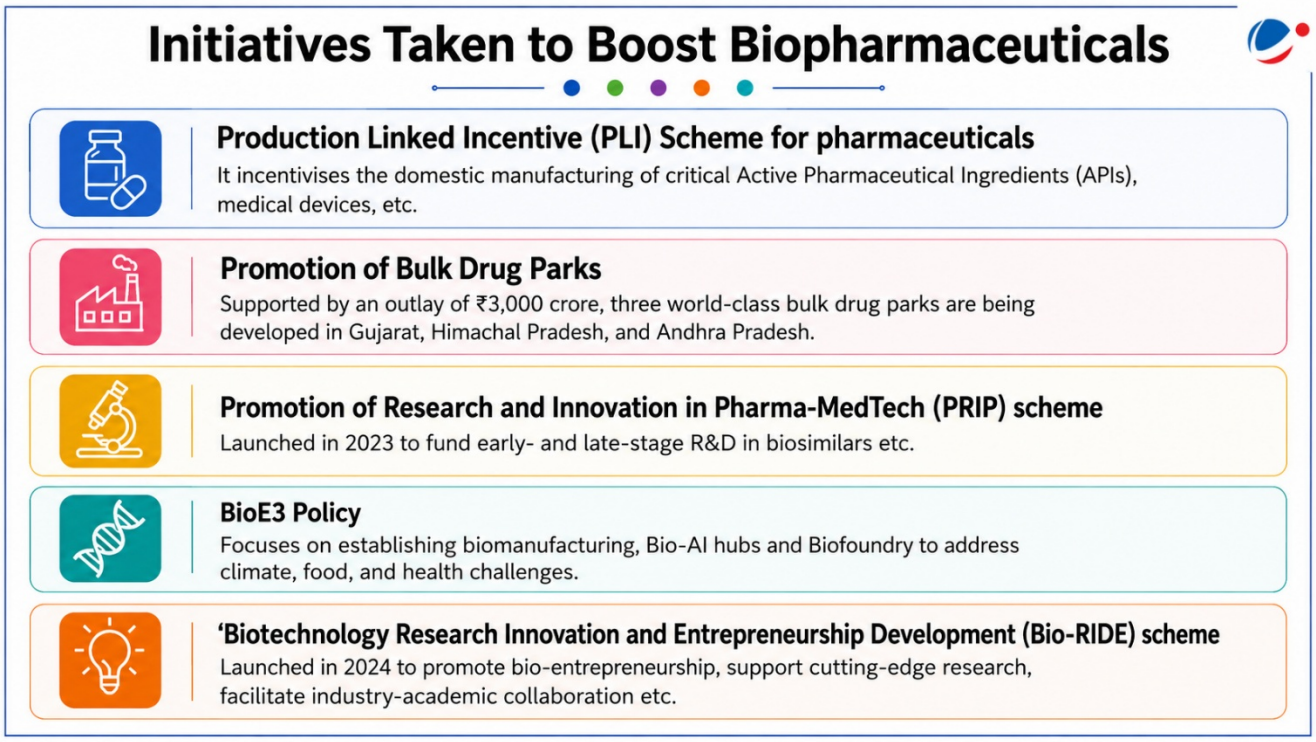
- **Biosimilars** are copies of biologics that are highly similar to biologics and have no clinically meaningful differences from the reference product.

About Biopharma

- **Definition: Biopharma or biopharmaceuticals** involves production, manufacturing, or extraction of therapies through biological organisms, such as human cells, fungi, or microbes.
- It **is subsector** of the larger economic sector called as **Bioeconomy.**

Challenges of the biopharmaceutical industry in India

- **Multiple agencies:** Industry is governed by multiple agencies, including the CDSCO and various state drug control authorities with slow regulatory approval processes.
- **International compliance:** Internationally, meeting the stringent standards of bodies like the US FDA and European Medicines Agency (EMA) is both resource-intensive and time-consuming.
- **Supply Chain Vulnerabilities:** Industry is heavily dependent on imported Active Pharmaceutical Ingredients (APIs), primarily from China, making the industry vulnerable to geopolitical tensions or global crises.
- **Patent Conflicts**: Conflicts with multinational pharmaceutical companies over patent rights and patent "evergreening" are frequent, leading to costly and time-consuming legal battles.


Initiatives Taken to Boost Biopharmaceuticals
Production Linked Incentive (PLI) Scheme for pharmaceuticals
It incentivises the domestic manufacturing of critical Active Pharmaceutical Ingredients (APIs), medical devices, etc.
Promotion of Bulk Drug Parks
Supported by an outlay of ₹3,000 crore, three world-class bulk drug parks are being developed in Gujarat, Himachal Pradesh, and Andhra Pradesh.
Promotion of Research and Innovation in Pharma-MedTech (PRIP) scheme
Launched in 2023 to fund early- and late-stage R&D in biosimilars etc.
BioE3 Policy
Focuses on establishing biomanufacturing, Bio-AI hubs and Biofoundry to address climate, food, and health challenges.
'Biotechnology Research Innovation and Entrepreneurship Development (Bio-RIDE) scheme
Launched in 2024 to promote bio-entrepreneurship, support cutting-edge research, facilitate industry-academic collaboration etc.

Conclusion

Biopharma SHAKTI scheme is designed to further strengthen domestic capabilities in biologics and biosimilars through targeted investments in workforce development, nationwide clinical trials infrastructure and enhanced regulatory capacity, reinforcing India's ambition to become a global biopharma manufacturing hub.

2.2. GENE EDITING AT A GLANCE

Gene Editing

- Gene editing is a technology that can change DNA sequences at one or more points in the strand.
- It also involves removing or changing a single base or insert a new gene altogether.
- The process involves three major steps that include insertion, deletion, and modification of the gene of interest.

Techniques used for Gene Editing

ZFNs (Zinc Finger Nucleases):
Zinc finger proteins (targeting) + FokI enzyme (cutting)

TALENs (Transcription Activator-Like Effector Nucleases):
TALE proteins (targeting) + FokI enzyme (cutting)

CRISPR-Cas9:
Guiding RNA molecules + Cas9 enzyme (cutting)

Applications of Gene-Editing

Agriculture:
E.g., India's first genome-edited rice varieties named as DRR Rice 100 (Kamla) and Pusa DST Rice.

Functional de-extinction:
E.g., Colossal Biosciences bringing back the Dire Wolf by using cloning and gene editing techniques.

Space:
E.g., NASA experiments with CRISPR to assess DNA repair in microgravity for future long-term missions.

Enhancing Livestock Productivity:
India's first gene-edited sheep has been produced by researchers from Kashmir University in collaboration with ICAR.

Material:
E.g., Spider Silk Production Modified silkworms create steel-stronger silk.

Challenges related to Gene-Editing

Bioterrorism:
E.g., bioweapons by modifying pathogens to be more virulent or drug-resistant.

Off-target Effects:
Gene-editing tools may unintentionally alter DNA at unintended sites.

Germline Editing Risks:
Heritable changes can impact future generations without consent.

Animal Welfare Concerns:
As creating genetically edited animals often involves sacrificing some animals and performing surgical procedures.

Eugenics:
Promoting the idea of "improving" humans and increasing discrimination.

Way Forward

Altruistic Science:
Research must be designed to increase human health and wellbeing.

Consensus-based application:
Genome editing for reproductive purposes should be stopped until a social consensus is reached.

Last Resort to treatment:
Human germline editing should be permitted only when there is no reasonable alternative for disease prevention

Robust policy framework:
Ensuring accountability and self-regulation.

2.2.1. CRISPR

Why in the News?

India launched its 1st indigenous CRISPR-based gene editing therapy called BIRSA-101 for Sickle Cell Disease.

More on the News

- It has been **developed by CSIR–Institute of Genomics & Integrative Biology (IGIB).**
- It has been called **BIRSA-101** as it has been dedicated to Bhagwan Birsa Munda on his **150th birth anniversary.**

CRISPR Technology

- **CRISPR** stands for Clustered Regularly Interspaced Short Palindromic Repeats.
- **CRISPR** leverages a **natural defense mechanism of bacteria** to cut DNA at a specific location.
- **It involves two key molecules:**
  - **Guide RNA:** Designed to find and bind to specific parts of the target genome.
  - **Cas9 (CRISPR-associated protein 9):** It acts as molecular scissors that can cut two strands of DNA.
- **Working:**
  - When bacteria are attacked by a virus, **they record a section of the virus's DNA** in their own DNA.
  - **Storing part** of the virus's genetic code allows the bacteria to **"remember"** it.
  - **When the same type of virus attacks** again, the bacteria use a specific CRISPR-associated protein number 9 (CAS9) to cut the virus's DNA, destroying the virus.
    - **The 2020 Nobel Prize for Chemistry** was awarded for their discovery.
- **Applications**: Edit genes in human embryo; Change genetic codes of **crops to improve crop resilience**; creating new therapies for **Cancer treatment & sickle cell diseases** etc.

Conclusion

CRISPR represents one of the most significant breakthroughs in modern biology, with the potential to address global challenges in health, food security, and environmental sustainability, provided its application remains guided by ethical and regulatory safeguards.

2.2.2. GENE THERAPY

Why in the News?

First-Ever Gene Therapy for Treatment of Genetic Hearing Loss called Otarmeni approved.

Key Highlights of the Approved Therapy

- **Otarmeni is made by** Regeneron Pharmaceuticals was approved by United States Food and Drug Administration under National Priority Voucher Program.
- **OTOF Gene Mutation:** Therapy is designed to treat hearing loss caused by **OTOF gene mutations.**
  - **OTOF Gene** codes for a **protein called otoferlin**, needed by inner ear cells to translate vibrations into signals interpreted by brain.

About Gene Therapy

- **Definition:** It is a technique that uses a gene(s) to treat, prevent or cure a disease or medical disorder.
  - In most gene therapy, a normal gene is inserted into the genome to supplement an abnormal disease-causing gene and restore the target cell to a normal state**.**

- **Vectors:** Vector refers to the carrier used for delivering the therapeutic gene to the patient's target cells.
- **Types of Gene Therapy**
  - **Germline gene therapy:** Germline Cell (egg or sperm) are modified by the introduction of functional genes, which are integrated into the genome. It is **inheritable.**
  - **Somatic cell gene therapy**: In this, therapeutic gene are transferred to a patient's somatic cells (cells other than germline cells). Any modification and any effects are restricted only to that patient and **are not inherited** by future generation.
- **Application:** Both inherited genetic diseases (e.g., haemophilia and sickle cell disease) and acquired disorders (e.g., leukaemia) could be treated with gene therapy.

Conclusion

Gene therapy marks a new frontier in modern medicine, offering the promise of durable and potentially curative treatments for genetic diseases. With robust regulation, ethical safeguards, and inclusive access, it can become a cornerstone of future healthcare and personalized medicine.

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2.3. GENOME SEQUENCING AT A GLANCE

Genome sequencing

It is process of determining complete genetic material sequence of an organism's genome. It determines the precise sequence (A, T, C, G and U) of nucleotide bases in DNA/RNA strand.

Whole Genome Sequencing determines the entire DNA sequence of an organism's genome and covers both coding (exons) and non-coding (introns, regulatory regions) regions of DNA.

Key applications of Genome Sequencing

Disease Diagnosis: E.g., **BRCA1** and **BRCA2** gene sequencing helps assess breast and ovarian cancer risk.

Anthropology: E.g., DNA sequencing has played role in understanding human migration and ancestry.

Agriculture: E.g., **International Wheat Genome Sequencing Consortium** improved disease resistance.

Vaccine Development: E.g., During COVID-19, it is used by **INSACOG** was used to detect and monitor emerging variants like **Delta** and **Omicron.**

Initiatives taken for Genome Sequencing

IndiGen program: To, undertake whole genome sequencing of thousands of individuals representing diverse ethnic groups from India.

One Day One Genome initiative: To make microbial genomics data more accessible to researchers.

Human Genome Project (HGP): aimed to map and sequences the entire human genome.

International HapMap Project: To identify genetic links to diseases, aids in diagnostic tool development.

Global Alliance for Genomics and Health (GA4GH): Sets standards to expand genomic data use.

Challenges related to Genome Sequencing

Data Accuracy: Sequencing technologies still grapple with errors, particularly in long-read sequencing.

Privacy: Sensitive information such as genetic composition, medical and family history.

Lack of regulatory framework: It limits quality and proficiency standards and leads to misuse of data.

Data Storage: Genome sequencing generates massive data (each genome ~200 GB).

Discrimination based on genetic information: It may prevent access to health benefits such as insurance.

Way Forward

Technologies: E.g., Upgrade existing biotechnology labs with next-generation sequencing **(NGS)** technology which can rapidly sequence large amounts of DNA or RNA.

Establish national bioethics committees for oversight and public engagement.

Global best practices e.g., Genetic Information Non-discrimination Act **(GINA)** of US.

Robust Data Infrastructure: Establish secure and scalable cloud-based platforms for storage, analysis, and sharing of genomic data.

2.3.1. GENOME INDIA PROJECT (GIP)

Why in the News?

The data from the GIP was compared to existing global databases in a study.

Key Findings of Study

- **Genetic Variants:** Over 129 million genetic variants were identified.
- **Endogamy (marriage within communities)**: has resulted in genetically distinct and isolated groups.
- **Contrasting Population Dynamics: Non-tribal populations:** greater genetic mixing and population growth.
- **Tribal populations:** low effective population size, high genetic drift, and strong founder effects (certain rare global variants become locally common due to prolonged isolation).

About Genome India Project (GIP)

- **Launched:** in **2020** by Department of Biotechnology (DBT), under the **Ministry of Science and Technology**.
- It is an **Indian equivalent of the Human Genome Project (HGP)**, a global-level effort to map human genomes, launched in October 1990 and completed in April 2003.
- **Objective**: To build a comprehensive catalogue of genetic variations that reflects the unique diversity of the Indian population.
- **Sample Size and Diversity:** The study collected samples from **10,000 healthy and unrelated individuals**.
- These individuals represent **83 distinct population groups** and span India's **four prominent linguistic families**: Indo-European, Dravidian, Austro-Asiatic, and Tibeto-Burman.

Significance:

- **Healthcare: Disease prediction and early diagnosis** with better disease gene discovery**, population-specific diagnostics** (e.g., impact of endogamy on diseases), etc.
- **Reduces Bias:** as global genetic databases remain dominated by European populations.
- **R&D:** Boosts India's and global genomic research and innovation ecosystem.

Conclusion

The Genome India Project is akin to the Human Genome Project on a global scale but focuses on the diverse Indian demographic, which was under-represented in previous studies. The project aims to expand the genetic database by adding more samples, creating a comprehensive gene bank of Indian populations.

2.4. STEM CELL THERAPY

Why in the News?

The Supreme Court (SC) has categorically barred medical practitioners from offering stem cell therapy (SCT) as a treatment for autism spectrum disorder (ASD).

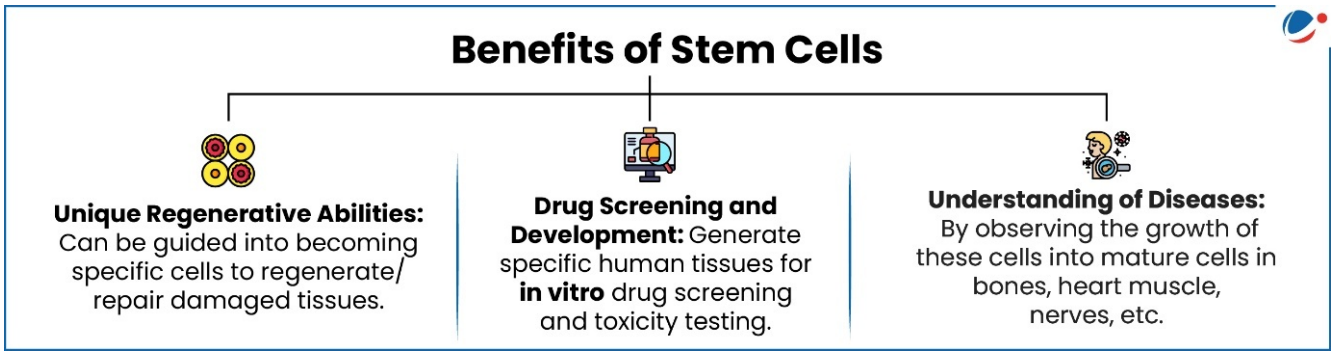
About Stem Cell Therapy (SCT)

- A form of **regenerative medicine** designed to repair damaged cells within the body by reducing inflammation and modulating the immune system.
- **Standard application:** Leukemia and Lymphoma, Parkinson's Disease etc.
  - **ICMR (2021)** recognizes stem cell therapy as standard treatment only for hematological disorders (disorders of the blood and blood-forming organs).
- **Advantages:** Enables tissue regeneration; targeted treatment and potential cures, especially in diseases where conventional therapies are limited etc.

Abut Stem Cell

- **Stem Cells** are **unspecialized cells** that can **self-renew indefinitely** and can also **differentiate into more mature cells** with **specialized functions.**

- **Types:**
  - **On the basis of Source:** Embryonic Stem Cells (ESCs), Adult/Somatic Stem Cells, Induced pluripotent stem cells (iPSCs), etc.
  - **On the basis of Differentiation Potential:** E.g., Totipotent cells (able to differentiate into all possible cell types), Pluripotent cells (Differentiated into most tissues of body but are unable to produce all tissue), etc.


Benefits of Stem Cells
Unique Regenerative Abilities: Can be guided into becoming specific cells to regenerate/ repair damaged tissues.
Drug Screening and Development: Generate specific human tissues for in vitro drug screening and toxicity testing.
Understanding of Diseases: By observing the growth of these cells into mature cells in bones, heart muscle, nerves, etc.

Issues with SCT

- **Proof of efficacy**: It lacks proven safety and efficacy and is not recommended by Indian Council of Medical Research (ICMR) and NMC (National Medical Commission).
- **Unethical commercial use:** Offering it as routine treatment violates accepted medical standards and ethics (Bolam test).
- **Consent Not Absolute:** Patient autonomy under **Article 21** does not extend to choosing unproven, unsafe therapies.
- **Research-Only Permission:** It is allowed only in approved clinical trials, with regulatory and ethical safeguards.
- **Professional Misconduct:** Its use, promotion or advertisement amounts to professional misconduct under NMC norms.

Conclusion

Stem Cell Therapy represents a major advancement in regenerative medicine, offering hope for treating chronic and degenerative diseases. However, scientific validation, ethical safeguards, and strict regulation remain essential for its safe and effective use.

2.5. CAR T-CELL

Why in the News?

India unveils its first Indigenous CAR-T Cell Therapy, NexCAR19 therapy.

About NexCAR19 therapy

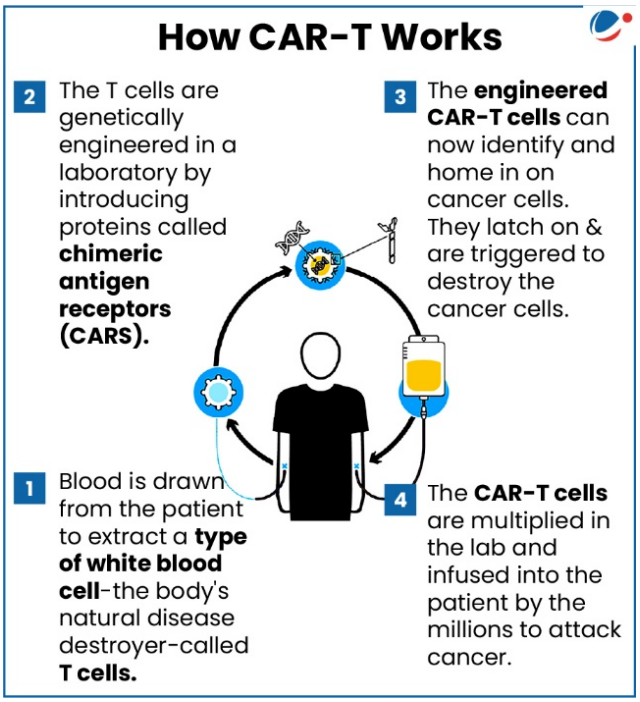
- It was **developed for B-cell blood cancers by ImmunoACT** (a company incubated under IIT Bombay, and Tata Memorial Hospital), supported by DBT and BIRAC.
- **It** was granted **market authorization** by the Central Drugs Standard Control Organisation **(CDSCO) in 2023.**

About CAR (Chimeric Antigen Receptor) T-Cell Therapy

- It **modifies immune cells**, specifically T-cells, by turning them into potent cancer fighters known as CAR-T cells.
  - T-cells are **special cells (types of white blood cells)** whose primary function is cytotoxic, meaning killing other cells.
- This treatment is **designed for specific types of blood cancer** and is given to patients whose cancer has either relapsed or not responded to first-line treatment.

Benefits of CAR T-Cell therapy

- **Short treatment duration:** Unlike aggressive chemotherapy or stem cell transplants, it allows for a faster recovery.
- **Sustained Benefits:** CAR T-cells persist in the body, offering long-term protection against cancer relapse.
- **Accessibility:** Nexcar19 cost is lower compared to imported CAR-T therapies.


How CAR-T Works
2 The T cells are genetically engineered in a laboratory by introducing proteins called chimeric antigen receptors (CARS).
3 The engineered CAR-T cells can now identify and home in on cancer cells. They latch on & are triggered to destroy the cancer cells.
1 Blood is drawn from the patient to extract a type of white blood cell-the body's natural disease destroyer-called T cells.
4 The CAR-T cells are multiplied in the lab and infused into the patient by the millions to attack cancer.

Challenges in adoption

- **Cytokine Release Syndrome (CRS)**: CAR T-cells leads to the release of abundant cytokines into the bloodstream, triggering an intensified immune system response.
- **Neurological Toxicity:** It leading to confusion, seizures, or other neurological issues.
- **Patient Eligibility:** factors such as age, overall health, and the presence of certain pre-existing conditions can impact eligibility
- **Other issues:** high cost, Limited Applicability (Only successful in certain blood cancers), etc.

Conclusion

There is need for enhanced safety profiles for minimizing severe side effects such as cytokine release syndrome and increased accessibility by integrating it in healthcare system.

2.6. MITOCHONDRIAL TRANSPLANTATION

Why in the News?

Groundbreaking Trial in UK Reported of the First Babies Born after Mitochondrial Donation Treatment.

What is Mitochondrial Disease?

- **Mitochondria:** They are tiny "power plants" inside almost every cell in our body**.** They generate more than 90% of the energy in cells.
- **Mitochondrial DNA:** Mitochondria have their own DNA, distinct from nuclear DNA. Affects energy production but not physical characteristics.
- **Mitochondrial Disease:** When the mitochondria **are not working properly**, cells don't have **enough energy** and they **begin to die.** When **too many cells die**, **whole organ systems can fail**, which **can be life-threatening.**
  - Mitochondrial diseases are **exclusively inherited from the child's mother.**

About Mitochondrial Replacement Therapy (MRT)

- **Definition of MRT:** It is a new form of reproductive invitro fertilization (IVF) which works on the principle of replacing a women's abnormal mitochondrial DNA (mt-DNA) with the donor's healthy one.
- **In MRT an embryo contains:**
  - **Nuclear DNA** from **a man** and **a woman** (the prospective mother)

- **Mitochondria in an egg** donated by another woman (the mitochondrial donor).

- **Since,** the child born will **have three distinct genetic materials**, it is called **a "Three-Parent Baby".**
- **Techniques:** MRT include different techniques like **Maternal Spindles Transfer (ST), Pronuclear Transfer (PNT).**

Pronuclear Transfer Technique (PNT)	Maternal Spindle Transfer (MST) Technique
• Done **after fertilization.** • **Parents' genetic material is moved** from their fertilized egg into the donor's egg with healthy mitochondria. • Results in **embryo with parents' DNA and donor's healthy mitochondria.** • **Less than 5% carryover** of defective mitochondria.	• Done **before fertilization**. • Mother's genetic material is **moved from her egg into donor's egg** with healthy mitochondria. • **Reconstructed egg is then fertilized** with the father's sperm. • Preferred method due to **lower risk of defective mitochondria carryover.**

Conclusion

Mitochondrial transplantation is a promising regenerative therapy for degenerative joint conditions. Future research should focus on standardizing bioengineered mitochondrial transplants to enhance their efficiency and effectiveness.

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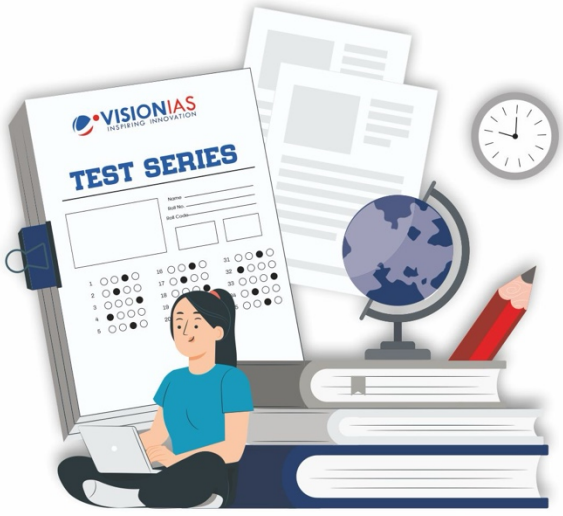

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2.7. NANOTECHNOLOGY AT A GLANCE

Nanotechnology

Refers to the **design, characterization, production and application** of structures, devices and systems by **controlling shape and size at the nanoscale.**

Nanoscale refers to dimensions between approximately **1 and 100 nanometers.**

Key applications of Nanotechnology

Energy:	**Food Safety:**	**Water Management:**	**Electronics:**	**Environment:**
E.g., A semiconductor developed by Kyoto University can enable solar panels to convert nearly twice as much sunlight into electricity.	Nano biosensors could be used to detect the presence of pathogens in food.	E.g., nano-enabled reverse osmosis systems.	E.g., Carbon nanotubes are close to replacing silicon as a material for making smaller, faster and more efficient microchips.	E.g., Detects contaminations such as mercury ions in lake water.

Initiatives taken to promote Nanotechnology

Nano Science and Technology Initiative (NSTI):	**Mission on Nano Science and Technology (Nano Mission):**	**Indian Nanoelectronics Users Programme-Idea to Innovation (INUP-i2i)**	**Nano Science and Technology (INST),**
Initiated in 2002 to promote research and advelopment in advanced area of Nano S&T.	Launched in 2007, provides critical funding to competent groups) to carry out research in Nanoscience.	initiated by MeitY for undertaking research and skill development.	first Nano-Science Institute at Mohali, Punjab.

Challenges related to Nanotechnology adoption in India

Impact on Health:	**Lack of Skill Work Force:**	**Ethical Concern:**	**Other:**
Nano-sized spherical solid materials will easily enter the lungs and reach the alveoli.	Number of students following undergraduate and graduate degrees in the area is low.	E.g., nano-based products may be used in warfare, invade people's privacy etc.	High costs for acquisitions of IPR, lower participation of private sector in R & D, etc.

Way Forward for nanotech development in India

Promote Industry–Academia Collaboration:	**Build Skilled Human Resource:**	**Increase Private Sector Investment:**
E.g., Collaboration between research labs and fertilizer companies for commercialization of nano-fertilizers.	E.g., Specialized nanoscience programs in leading IITs and research institutions.	E.g., Provide tax incentives, venture funding, and incubation support for nanotechnology startups.

2.7.1. NONTECHNOLOGY IN HEALTHCARE AT A GLANCE

Nanotech and Healthcare

Nanotechnology along with other emerging technologies like AI is paving way for the precision medicine in the health care.

Applications of Nanotech in Healthcare

Clinical investigation: E.g., Gold nanoparticle is used for the detection of targeted sequences of nucleic acids, as potential treatments for cancer.

Targeted Drug Delivery: E.g., Nanotech materials can contain hydrophobic and hydrophilic drugs, protect drugs from chemical and enzymatic degradation etc.

Regenerative Medicine: E.g., Nanofiber scaffolds for skin regeneration in burn patients.

Smart Implants and Medical Devices E.g., Nano-coated orthopedic implants for better bone integration.

Challenges related Nanotech in Healthcare

Toxicity: E.g., cobalt and chromium nanoparticles cross skin barrier and damage fibroblasts.

Treatment Costs: Nanoparticle-based cancer drugs often carry a higher upfront cost than conventional treatments.

Scalability Issues: Synthesizing nanomaterials on a large scale while maintaining uniformity and quality remains a significant challenge.

Way forward to effectively use Nanotech in Healthcare

Strengthen Safety: Establish dedicated nanotoxicology research centres for clinical evaluation of nanomedicines.

Invest in Advanced Diagnostic Technologies: Support the development of nano-biosensors and point-of-care diagnostic devices.

Strengthen Healthcare Infrastructure: Use of nano-based diagnostic kits in rural health centres for early disease detection.

2.7.2. NANOTECH & AGRICULTURE AT A GLANCE

Nanotech and Agriculture

Nanotechnology offers promising applications in agriculture, potentially revolutionizing crop production and management.

Applications of NanoTech in Agriculture

Nano fertilizers: Enhance nutrient-use efficiency and reduce fertilizer wastage.
E.g., **Nano Urea.**

Nano pesticides: reducing toxicity, improving the shelf-life, and increasing the solubility of poorly water-soluble pesticides.
E.g., **Nano Silver.**

Food Processing: E.g., Nanoemulsions minimize the requirement for stabilizers, owing to their protection against food breaking and split-up.

Smart Soil Health Monitoring: E.g., **Nano-sensors** provide real-time information on soil nutrients, moisture, and pH.

Climate-Resilient Agriculture: E.g., **Silicon nanoparticles (SiNPs)** effectively mitigate drought stress in crops.

Initiatives for Promotion of Nanotech in Agriculture

Guidelines for evaluating nano-agri inputs and products: Released by the **Department of Biotechnology.**

National Agricultural Innovation Project (NAIP): Several projects have been initiated to explore the applications of nanotechnology in agriculture.

Skill development training programme on nanotechnology: By **Indian Council for Agriculture Research (ICAR)**

Nano Fertilizer Plant (NFP): Established by **IFFCO** at **Phulpur, Prayagraj.**

2.7.3. NANOTECH & ENVIRONMENT AT A GLANCE

Nanotech and Environment

Organisation for Economic Co-operation and Development (OECD) suggests that **nanotechnology** offers environmental benefits in the following principle areas: **cleaner production, pollution reduction, and other environmental benefits.**

Applications of Nanotech in Environment

Sustainable Production: Green chemistry: Synthesis and processing of nanoscale materials will reduce consumption of raw materials and natural resources.	**Oil Spill Remediation:** Magnetic nanoparticles (MNPs) are used to clean marine oil spills.	**Water treatment:** Graphene filters can help in cleaning water.	**Reduction in energy Consumption:** Carbon nanotubes can be used in super-capacitors, batteries, solarcells (also Carbon nanoflorets) etc.	**Antimicrobial Action:** Carbon dots (CDs) generate reactive oxygen species (ROS) under visible or natural light, effectively killing bacteria.

Challenges related to Nanotech in Environment

Energy-Intensive Production: Production of carbon nanotubes (CNTs) relies on high-temperature processes to vaporize carbon or break down carbon-containing gases.	**Bioaccumulation:** Once microplastics are in the ocean, they break down into even tinier particles (called nano plastics) and accumulate in the food chain.	**Waste Disposal:** Nanomaterials from electronic waste entering landfills and water bodies.

Way forward to utilize nanotechnology in Environment

Strengthen Regulatory Frameworks E.g., European Union has introduced regulations under REACH (Registration, Evaluation, Authorisation, and Restriction of Chemicals) to assess risks of chemicals and nanomaterials.	**Promote Green Nanotechnology** E.g., Plant-based synthesized nanomaterials can effectively remove toxic contaminant.	**Invest in Long-Term Risk Assessment** E.g., OECD runs programs on nanoparticle safety testing.

2.8. KEY WORDS

Keywords			
Biopharma SHAKTI	**CRISPR-Cas9**	**BIRSA-101**	**Genome India Project (GIP)**
Stem Cell Therapy (SCT)	**CAR-T Cell Therapy**	**Mitochondrial Replacement Therapy (MRT)**	**Nanotechnology**

2.9. PRACTICE QUESTION

India's development of NexCAR19 marks a major milestone in advanced biotherapeutics. Discuss its significance and the challenges associated with CAR-T Cell Therapy.			
Introduction	**Body Part 1**	**Body Part 2**	**Conclusion**
CAR-T Cell Therapy and NexCAR19 breakthrough	Significance of CAR-T Cell Therapy	Challenges in Adoption of CAR-T Cell Therapy	Way forward for accessible cancer care.

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3. AWARENESS IN SPACE

3.1. SPACE PROGRAMME OF INDIA

Why in the News?

Recently, Lok Sabha held a special discussion on Critical Role of the Space Programme for Viksit Bharat by 2047.

Critical Role of Space Programme/Technology

Space programme/Technology will play a pivotal role in addressing **India's critical challenges** while simultaneously **unlocking new opportunities** for **growth** and **development**

Sector/Sphere	Current Challenges	Space-based Solutions
Agriculture & Food Security	**Erratic monsoons** due to climate change; low farm productivity; poor crop forecasting	**INSAT-3D/3DR** provide weather forecasting; **Resourcesat** supports crop monitoring and yield estimation
Infrastructure	**Lack of integrated planning;** delays in project implementation	**PM Gati Shakti** uses **ISRO imagery** & spatial tools to integrate projects like Bharatmala, Sagarmala, railways, etc.
Disaster Management	**High vulnerability to floods**, cyclones, landslides, earthquakes, forest fires	**ISRO's Disaster Management Support (DMS) Programme** enables real-time monitoring, early warning, and post-disaster assessment
Security & Defence	**Border surveillance gaps**; communication vulnerabilities; emerging space threats	**GSAT-7 & RISAT** strengthen secure communication & surveillance; **Mission Shakti (2019)** demonstrated anti-satellite capability
Healthcare Delivery	**Limited access to healthcare** in remote areas	**ISRO's Telemedicine Project**
Education	**Rural-urban education divide**; limited digital learning infrastructure	**EDUSAT** provides distance learning & educational broadcasting
Transparency & Accountability	**Leakages & poor monitoring** in welfare schemes	**Geo-tagging of MGNREGA assets** ensures accountability and transparency
Water Management	Depletion of groundwater; poor watershed planning	**Bhuvan–SRISHTI Geoportal** enables monitoring of Integrated Watershed Management Programme (IWMP) projects

How progress in Space Sector makes India Vishwabandhu?

- **Global Collaboration: E.g.,** NISAR is termed "**India's scientific handshake with the world**", symbolizing international collaboration.
- **Regional Leadership and Support**: Launched **South Asia Satellite (GSAT-9)** for the South Asian region (except Pakistan).
- **Sharing Technology, Expertise, & Data for Universal Benefit:** E.g., **Chandrayaan-3** datasets are available on PRADAN (Policy based data Retrieval, Analytics, Dissemination and Notification system) for the scientific community.
- **Capacity Building Initiatives**: Programs like **UNNATI (UNispace Nanosatellite Assembly & Training by ISRO)** offer international training on nanosatellite development.
- **Cost-Effectiveness & Reliability: E.g.,** Mars Orbiter Mission (MOM) was most economical interplanetary mission in the world.
- **Humanitarian Aid**: ISRO is member of the COSPAS–SARSAT, an international satellite-based search and rescue (SAR) system.

Conclusion

India's space programme is a driver of national growth, global cooperation, and sustainable development. With clear milestones such as establishing the Bharatiya Antariksh Station (BAS) by 2035 and launching a crewed lunar mission by 2040, India is steadily positioning itself as a leader in space exploration.

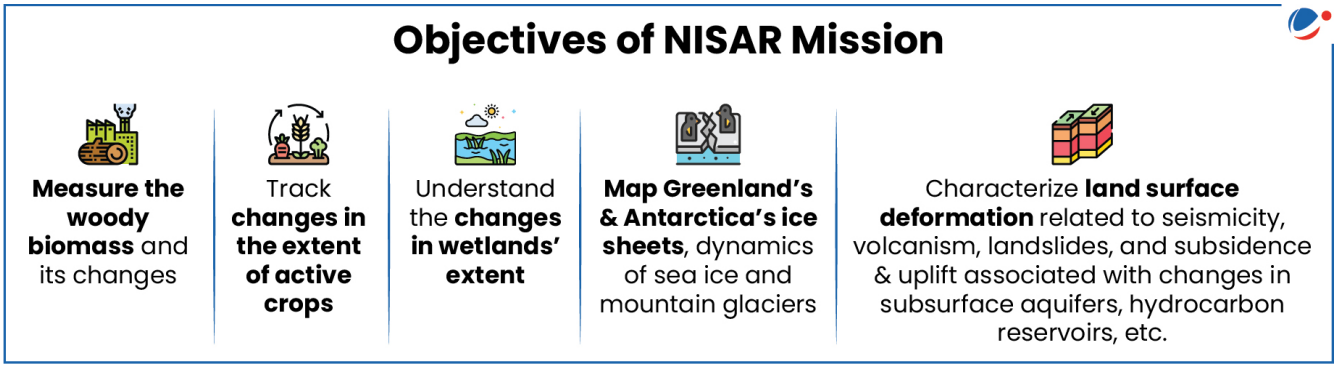
3.2. NISAR (NASA-ISRO SYNTHETIC APERTURE RADAR)

Why in News?

The NISAR satellite was successfully launched from Satish Dhawan Space Centre, Sriharikota.

About NISAR satellite

- NISAR is a global, **microwave imaging mission, with capability to acquire fully polarimetric and interferometric data.**
- **Developed** jointly by **ISRO** and **NASA**.


Objectives of NISAR Mission
Measure the woody biomass and its changes
Track changes in the extent of active crops
Understand the changes in wetlands' extent
Map Greenland's & Antarctica's ice sheets, dynamics of sea ice and mountain glaciers
Characterize land surface deformation related to seismicity, volcanism, landslides, and subsidence & uplift associated with changes in subsurface aquifers, hydrocarbon reservoirs, etc.

- **Launch Vehicle:** ISRO's Geosynchronous Satellite Launch Vehicle (GSLV)-F16.
- **Orbit:** Sun Synchronous Polar Orbit (SSO)
  - **SSO** is kind of polar orbit where **satellites** are in sync with Sun, matching earth's rotation around sun and appearing to be in the same position relative to sun.
- **Mission Life:** 5 years

Technical Features

- **Repeat Cycle:** Provides high-resolution data every 12 days to monitor land changes across Earth.
- **SweepSAR (Swept Synthetic Aperture Radar)**: Used in radar imaging to produce high-resolution, wide-swath images across a broad range of terrain.
- **Dual-band Synthetic Aperture Radar (SAR):** L-band and S-band
- **Open-Data Policy:** Information collected will be freely available to global scientific community.

Significance of NISAR for India

- **Disaster Management:** Assess natural hazards such as earthquakes, tsunamis, volcanic eruptions, and landslides by tracking subtle changes in the Earth's crust and surface movements.
- **Agricultural Monitoring:** Tracks soil moisture, crop health, and acreage for better farm planning.
- **Climate and Environmental Protection**: Track ecosystems and climate impacts through sea ice classification, shoreline monitoring, storm tracking, and ship detection**.**
- **Water Resource Management:** Assists in tracking groundwater stress and watershed changes.

Conclusion

NISAR is a powerful tool for sustainable development, disaster preparedness, and climate resilience. For India, it marks a leap in Earth observation capability, ensuring better planning, policy-making, and fulfilment of developmental goals.

3.3. AXIOM-4 MISSION

Why in the News?

Axiom-4 Mission carrying **Indian astronaut** Group Captain **Shubhanshu Shukla** and 3 other astronauts successfully returned on July 15, 2025.

About Axiom-4 (Ax-4) Mission

- It is the **4th private astronaut mission,** to the **International Space Station (ISS),** of private US Company **Axiom Space** in collaboration with **NASA** and **SpaceX.**
- **Aim**: To "realize the return" to human spaceflight for **India, Poland, and Hungary.**
- Following research and activities have been **executed by ISRO**:
  - **Crop growth**: Study impact of microgravity on **6 crop** seed varieties for future space farming.
  - **Cyanobacteria:** Observe growth and activity for use in spacecraft life support systems.
    - **Cyanobacteria** are aquatic bacteria that can photosynthesize.
  - **Space Microalgae**: Compare metabolic and genetic activity in space vs Earth; potential use as food, fuel, or for life support.
  - **Myogenesis:** Study muscle loss, identify pathways responsible for **skeletal muscle dysfunction** in microgravity and explore therapeutic targeting strategies.
  - **Tardigrades**: Investigate the revival, survival, and reproduction of **tardigrades** to identify molecular mechanisms of resilience.

Axiom Mission's Significance for India

- **Development of Gaganyaan Mission:** Offers valuable inputs for medical training, psychological prep, and crew–ground coordination.
  - Group Captain **Shubhanshu Shukla** is one of the 4 astronauts selected for the **Gaganyaan mission.**
- **Space diplomacy**: Highlights ISRO's global collaborations with NASA, ESA, and private firms**.**
- **Development of India's Space Ecosystem:** Encourages growth of India's space industry; aligns with plans for Bharatiya Antariksh Station.
- **National Pride and inspiration:** Indian astronauts in space will inspire Indian youth to pursue careers in science, technology, engineering, and mathematics (STEM).

Challenges for India in launching a Manned Space Mission

- **Life support system:** Must ensure air regeneration, temperature control, waste recycling, and food storage.
- **Radiation protection:** Beyond Low Earth Orbit, cosmic radiation and solar particle events pose serious health risks.
- **Spacecraft re-entry and thermal protection:** During re-entry, spacecraft face temperatures up to **7,000°F** due to the compression of air and gas particles against their surface.
- **Launch vehicle reliability:** Human-rated rockets must meet **stricter safety standards** to address complexities including controlled ascent, abort systems, and reusability.
- **Higher cost:** Manned space missions incur **higher costs** due to requirement of robust ecosystems including launchpads, testing facilities, etc.
- **Training and selection of astronauts:** Astronauts require **rigorous physical**, psychological, and technical training.

About International Space Station (ISS)

- It is a **habitable artificial satellite**, in Low Earth orbit (LEO) (altitude of 370–460 km).
- **Key partners for ISS**: Europe (ESA), the USA (NASA), Japan (JAXA), Canada (CSA) and Russia (Roscosmos)
- It orbits the Earth at a speed of approximately **28,000 kilometres per hour**, completing **one orbit every 90 minutes**.

- It is the **largest artificial body in orbit** providing a **laboratory in space**, having an orbit such that it can fly over **90% of inhabited Earth.**
- Its **first** component was launched into orbit in **1998** and it will continue to be a working laboratory and outpost in orbit **until at least 2030**.

Conclusion

For India, the collaboration under Axiom-4 Mission, not only **accelerates technological learning** ahead of its proposed Gaganyaan mission but also builds **critical human capital and infrastructure** for future long-duration spaceflight.

3.3.1. ASTRONAUTS RE-ENTRY AND SAFE LANDING

Why in the News?

Returning home from space is a complex technical challenge that requires precise calculations regarding speed and entry angles.

Key Stages in Re-entry Process

- **Re-entry into Earth's Atmosphere (De-orbit Burn process):** Spacecraft fires engines in reverse to slow down, allowing Earth's gravity to pull it into the atmosphere.
- **Capsule uses** a heat shield to withstand extreme temperatures during re-entry.
- **Deploying Parachutes:** This plays role of natural brake that allows the capsule to float gently downward.
  - After this, Capsule lands either on land or in the ocean (splashdown).

Major Challenges during Atmospheric Re-entry

- **Hitting the exact re-entry angle:** Calculating the precise angle and speed of descent is crucial for the crew's survival.
  - If the angle is too steep, the friction will cause the spacecraft to completely burn up on re-entry, killing everyone on board.
- **Surviving immense heat:** Air rushing past it creates intense friction. Temperatures can easily exceed 1600°C—which is hot enough to melt steel—and can even rise to almost 4000°C.
- **Slowing down from extreme speeds:** Before re-entry, spacecraft travel much faster than the speed of sound, reaching speeds between 17,500 mph and 25,000 mph.
- **Communication blackout**: Extreme heat ionises air into a plasma sheath around the capsule. This acts like a metallic barrier that blocks radio signals, causing a temporary communication blackout.

ISRO's re-entry Capabilities

- ISRO first proved its ability to safely return an orbiting craft to Earth with the **Space Capsule Recovery Experiment (SRE)** in 2007.
- This was significantly advanced by the **2014 Crew Module Atmospheric Re-entry Experiment (CARE).**
- **ISRO** is developing a **winged Orbital Re-entry Vehicle (ORV)** that will be launched into orbit and then autonomously re-enter Earth's atmosphere to land on a runway like an aircraft.

Conclusion

Safe re-entry and landing are among the most critical phases of any human space mission, requiring advanced thermal protection, precision navigation, and robust recovery systems. As countries expand their human spaceflight capabilities, mastering these technologies remains essential for ensuring astronaut safety and the long-term success of space exploration.

3.4. IRNSS – NAVIGATION WITH INDIAN CONSTELLATION (NAVIC)

Why in the News?

Indian Regional Navigation Satellite System (IRNSS)-Navigation with Indian Constellation (NavIC) has suffered a major setback after the last atomic clock on board the IRNSS-1F stopped functioning.

More on the News

- This **leaves only 3 satellites** (IRNSS-1B, 1I, and NVS-01) of the NavIC constellation capable of providing PNT (Position, Navigation, and Timing) services.
- **At least 4 satellites with operational atomic clocks** are required for the navigation satellite system to function properly.

About Atomic clock

- **Definition:** High-precision **timekeeping devices** that utilize the **microwave transition of atoms (E.g., cesium, rubidium, or hydrogen)** to measure time with exceptional accuracy.
- **Atomic clocks** are so precise that they gain or lose **only one second every 100 million years**, as compared to one second in a few days for conventional clocks like those that are based on quartz.

About IRNSS – Navigation with Indian Constellation (NavIC)

- It is an **independent regional navigation satellite system** developed by **Indian Space Research Organisation (ISRO**).
- **Coverage:** To provide accurate **Position, Velocity and Timing (PVT) service** to users in India as well as to region extending about **1500 km beyond** Indian land mass.
- **Key services:**
  - **Standard Positioning Service (SPS**): Available for all civilian, provides position accuracy of better than **20 meters** and timing accuracy better than **40 nanoseconds** over the **service area.**
  - **Restricted Service (RS):** Encrypted service for **authorized users**.
- **Satellite Constellations:**
  - **First Generation:** Consists of **7 satellites**- 3 satellites in **Geostationary orbit (GEO)** and 4 in **Geosynchronous orbit** originally and a network of ground stations **operating 24 x 7.**
  - **Second-generation: NVS** (Navigation Satellite) series of satellites which incorporates **L1 band signals** additionally to widen the services**.**

Significance of functional IRNSS-NaVIC

- **Strategic Independence:** A non-functional NavIC forces India back onto total reliance on the US-owned GPS. **E.g.,** In 1999 Kargil War, USA denied **use of GPS**.
- **National Security**: IRNSS provides encrypted Restricted Service (RS) for armed forces, supports missile guidance, surveillance, and real-time troop movement.
- **Infrastructure support:** E.g., around 8700 trains are equipped with **NavIC** along with other GNSS constellations; Integration with GAGAN for aviation etc.
- **Global Interoperability**: SPS signals are interoperable with the other global navigation satellite system (GNSS) signals namely **GPS (USA), Glonass (Russia), Galileo (Europe)** and **BeiDou (China**).
- **Other support**: Disaster Management**;** Transportation (terrestrial, aerial and marine); location-based services, personal mobility; Surveying and geodesy; scientific research; time dissemination and synchronization etc.

Challenges related to NaVIC

- **Poor Launch Rate**: The constellation is deteriorating faster than it can be replenished, owing to ISRO's limited launch rate.
- **Organizational Overextension:** The absence of a **national space law forces ISRO** to act as both the designer and operator of NavIC.

- **Lack of management body:** India lacks a counterpart to the GPS Directorate and European Union Agency for the Space Programme (EUSPA), which respectively manage the GPS and Galileo constellations.

Conclusion

Department of Space is expanding NavIC's use across key sectors such as real-time train tracking, fishing vessel communication, vehicle tracking for passenger safety, and dissemination of Indian Standard Time (IST). It is also focused on fully Operationalizing NavIC for secure navigation by **completing the base constellation**, enhancing services based on user needs, and integrating **indigenous technologies like space-grade atomic clocks** to strengthen technological self-reliance.

3.5. ASTROSAT

Why in the News?

India's first dedicated space observatory, AstroSat, has completed 10 years since its launch**.**

About Astrosat

- **Objective:** India's first dedicated astronomy mission, designed to study celestial objects **across X-ray, ultraviolet, and optical wavelengths simultaneously**.
- **Launch**: Launched in **2015, aboard PSLV-C30** from Sriharikota.
- **Orbit:** Placed in **a low Earth orbit at 650 km altitude** for a minimum lifespan of 5 years.
- **Spectral Range:** The mission spans a broad energy band **from 0.3 keV to 100 keV**, covering near and far UV regions.

Scientific Objectives of AstroSat

- **Study High-Energy Phenomena**: To understand high-energy processes **in binary star systems containing neutron stars and black holes**.
- **Measure Magnetic Fields:** To estimate the magnetic fields of **neutron stars**.
- **Explore Star Formation:** To **study star birth regions** and high-energy activities in star systems beyond our galaxy.
- **Detect Transient X-ray Sources**: To identify **new, short-lived X-ray sources**.
- **Ultraviolet Universe Survey**: To conduct a limited deep-field survey of the universe in the **ultraviolet spectrum**.

Other Space and Ground observatories of India

- **XPoSat:** First dedicated satellite from ISRO to carry out research and **measure X-ray emission** from celestial sources.
- **Indian Astronomical Observatory (IAO), Hanle (Ladakh):** it hosts optical, infrared, and gamma-ray telescopes for astronomical and atmospheric studies.
- **Kodaikanal Solar Observatory (Tamil Nadu)**: One of India's oldest solar observatories.

Conclusion

AstroSat marks **a milestone** in India's space research, deepening multi-wavelength astronomy and strengthening global scientific collaboration while reflecting the **nation's growing self-reliance in space science**.

3.6. SATELLITE INTERNET

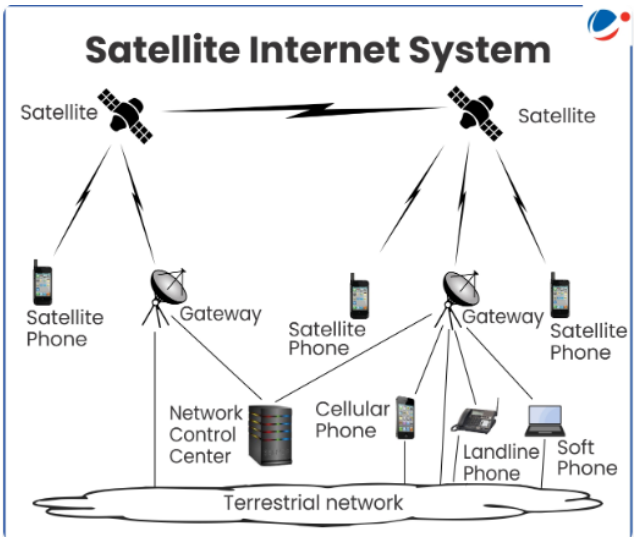
Why in the News?

Meghalaya becomes the third Indian state to partner with Starlink formally. Starlink (satellite internet constellation) was launched in 2019 by SpaceX and plans to have 42,000 satellites in Low Earth Orbit (LEO).

About Satellite Internet

- **Definition:** Satellite internet refers to the internet service provided through satellites placed in **Geostationary Orbits (GSO)** or **Non-Geostationary Orbits (NGSO).**

- **LEO and MEO** (Medium Earth Orbit) are NGSO.
- **Working:** Data is transmitted from a user's dish to a satellite and then to ground stations connected to the global internet.
  - **Low Earth Orbit (LEO)** satellites, like Starlink, offer faster speeds and lower latency than traditional geostationary ones.
- Unlike **land-based internet services** such as fiber, cable, etc., it **doesn't rely on wires** to **transmit data**, improving accessibility, deployment speed, and long-distance transmission.
- **Infrastructure**: It generally includes three segments:
  - **Space Segment:** Includes network of several communication satellites.
  - **Ground segment:** Includes satellite measurement and control networks, gateway stations, etc.
  - **User segment:** Includes communication terminals used by users.



Advantages over existing land-based internet services:

- **Global reach:** Connects remote and underserved regions lacking fiber or cellular infrastructure.
- **Rapid deployment:** Requires **only power** and **clear sky**, avoiding costly and time-consuming civil works.
- **Boost to Disaster Management:** Provides communication support in disaster-prone or geographically difficult areas (e.g., North-East India).
- **Support for Emerging Technologies:** Facilitates adoption of IoT, telemedicine, distance education, and smart agriculture in rural India.
- **Military and National Security Applications:** Already used by the Indian Army (e.g., Siachen Glacier) for robust internet access in high-altitude regions.

Issues about Satellite Internet services

- **Concerns for internal security:** In the wake of the Pahalgam attack, NIA suspect that terrorists may have used satellite phones to contact each other and their bases in Pakistan.
- **Monopolistic Tendencies:** SpaceX, with its extensive satellite network, risks forming a monopolistic market structure.
- **Satellite Latency:** Satellite internet typically has higher latency compared to traditional wired connections due to the distance, data must travel to and from the satellite.
- **High Cost for End-Users**: Much costlier than traditional broadband, limiting rural affordability.
- **Other:** Data Security Concerns, regulatory hurdles, National Security Issues etc.

Way forward

- **Comprehensive regulatory frameworks:** India must establish clear policies for licensing, data governance, and spectrum allocation.
- **Collaborating with private operators:** Incentives such as tax breaks and grants will encourage private players and ensure alignment with both national security objectives.
- **Hybrid models**: To maximize efficiency, hybrid models combining satellite and terrestrial networks can be used.
- **Security Instructions**: Department of Telecommunications (DoT) issued security instructions through amendments to the Unified License (UL).
  - **Geo-fenced coverage:** No User Terminal (UT) shall be able to access the network from outside the geo-fenced coverage area and/or through gateways situated outside India.
  - **Data Centre:** The licensee shall ensure that the Data Centre is based within Geographical boundary of India.

Conclusion

Satellite internet should complement terrestrial networks by focusing on rural, remote, and disaster-prone regions. Adopting hybrid connectivity models, reducing hardware costs, localizing pricing, and fostering collaboration with Indian telecom operators will be crucial to ensuring affordable and inclusive digital access

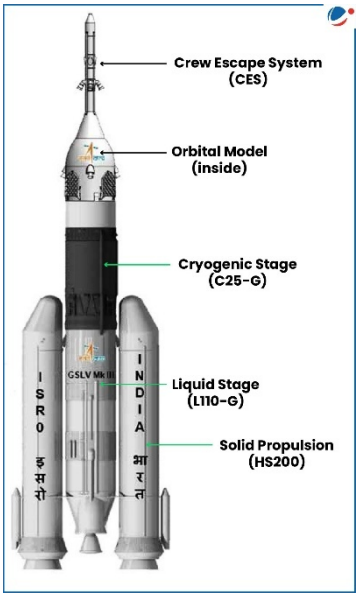
3.7. GAGANYAAN MISSION

Why in the News?

ISRO successfully conducted the second Integrated Air Drop Test for Gaganyaan, validating the Crew Module's parachute deployment sequence and safe descent.

About Gaganyaan Mission

- **Objective:** Demonstration **of human spaceflight capability** by launching **a crew of 3 members** to a **Low Earth Orbit (LEO) of 400 km** for a 3 days mission and bringing them back safely to earth, by landing in Indian sea waters.
- **Two unmanned missions** and **one manned mission** will be undertaken by ISRO.
- **Three Components of the Mission**
  - **Human Rated Launch Vehicle (HLVM-3):** ISRO's reliable heavy-lift launcher, **LVM3, has been re-configured** to meet **human rating** requirements. It is a **three-stage rocket**:
  - **Orbital Module:** A habitable space with Earth like environment in space for the crew that will be orbiting Earth comprises of
    - **Crew module:** Include environmental control and life support systems (ECLSS), parachutes.
    - **Service module:** An unpressurised bus carrying propulsion, power, thermal radiators, and water and oxygen tanks.
  - **Crew Escape System (CES):** CES is a **safety mechanism** designed to save the astronauts' lives if something goes wrong during launch.
- The **scope** of the Programme has been **extended** to include building of **first unit of the Bharatiya Anatriksh Station**



Significance of the Gaganyaan Mission for India

- **Space Diplomacy:** India will become **only the fourth nation** (following the **US, Russia, and China**) to possess an **independent human spaceflight capability**.
- **Advanced technology capability** for undertaking sample return missions and further space and scientific exploration (like Bharatiya Antariksh Station).
- **Foundation for Future Missions:** Serves as a stepping stone for India's planned space station and future lunar missions (e.g., Chandrayaan-4).
- **Other:** Economic Growth & employment creation; framework for wider Academia – Industry partnership in taking up development activities for national development.

About Bharatiya Antariksh Station (BAS)

- BAS is India's **planned space station for scientific research** which will orbit around **400 – 450km** above the Earth's surface. It will have **five modules**.
- **Targets: The first module** (the Base Module) **is targeted to be launched in 2028** and BAS to be operationalized by **2035**.

Conclusion

The **Gaganyaan Mission** is a landmark step in India's space program, advancing indigenous technology, strengthening scientific capabilities, and positioning India among leading human spaceflight nations while paving the way for future space exploration.

3.7.1. HOPE MISSION

Why in the News?

ISRO inaugurated Himalayan Outpost for Planetary Exploration (HOPE) analog mission in Tso Kar Valley, Ladakh.

About HOPE Mission

- **HOPE** is a specially designed Habitat Module for crew living and a Utility Module for operations and support systems which are interconnected for seamless workflow.
- **Led by:** ISRO's Human Space Flight Centre (HSFC), with industry partners and top Indian institutions.
- **Objectives**
  - Simulates **extraterrestrial environments** like the Moon and Mars.
  - Enables testing of human survival, health protocols, and equipment in space-like environments.
- **Studies to be conducted:**
  - Epigenetics, genomics, physiology, psychology.
  - Sample collection and microbial analysis techniques.
  - Validation of health monitoring and planetary surface operation protocols.
- **Why Tso Kar Valley was chosen?**
  - For Mars-like conditions: **High UV radiation**, **Low atmospheric pressure**, **Extreme cold** and **Saline permafrost**
  - Supports both **technological tests** and **astrobiology research**.
- Part of **broader analog missions trend globally**, aimed at preparing for long-term extra-terrestrial human missions.
  - **Other similar research stations across the World:** Mars Desert Research Station of the US, Flashline Mars Arctic Station of Canada, and BIOS-3 of Russia.

3.8. ADITYA-L1 MISSION

Why in the News?

ISRO's Aditya-L1 decodes the Impact of a Powerful Solar Storm on Earth's Invisible Magnetic Shield.

About Aditya-L1 Mission

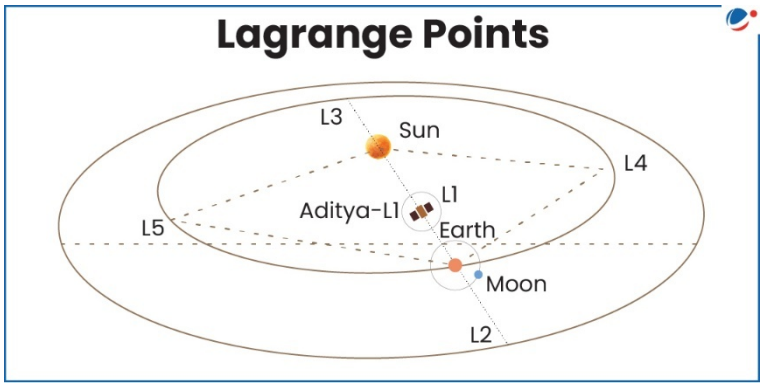
- It is **India's first dedicated solar mission.**
- It was launched in **2023** by PSLV-C57.
- **Objectives**: To understand Coronal Heating and Solar Wind Acceleration; flares and near-earth space weather; Solar wind distribution and coronal mass ejections etc.
- **Lifespan**: 5 years
- **7 payloads**:
  - **Remote Sensing Payloads**: VELC, Solar Ultraviolet Imaging Telescope (SUIT), etc.
  - **In-situ Payloads:** Aditya Solar wind Particle Experiment (ASPEX), etc.
- It is placed in a **halo orbit** around the **Lagrange point 1 (L1)** of the Sun-Earth system, which is about **1.5 million km from the Earth.**
  - **Halo orbit** is a periodic, three-dimensional orbit **at L**1 involving Sun, Earth and a spacecraft.
- At **Lagrange points**, the **gravitational pull** of two **large masses precisely equals the centripetal force required** for a **small object to move with them**.

What are Coronal mass ejections (CMEs)?

- **Causes:** This is often associated with **solar flares** and **active sunspot regions** where magnetic fields are strong and twisted.
- **Possible Impacts of CME on Earth:** Damaging satellite electronics and GPS communication, Power grid failures, Communication Disruptions e.g. radio signal disruption, aurora formation, radiation hazard to astronauts etc.

- These points are used to **reduce fuel consumption** needed to remain in position.

Significance of Solar Missions



- **Forecasting Space Weather:** Solar radiation and associated energy and magnetic fields can cause changes in the space weather impacting space technology and communications systems.
- **Understanding cosmic objects:** Sun being the closest star, its study can help in research about other stars.
- **Space Weather Prediction**: Improve forecasting of solar storms that can disrupt satellites, GPS, communication networks, and power grids.

Other Major Solar Missions

- **Hinotori (ASTRO-A)** launched by Japan in 1980s.
- **Parker Solar Probe** launched by US in 2018
- **Solar and Heliospheric Observatory Satellite (SOHO)** mission launched Jointly by NASA-ESA (longest-lived Sun-watching satellite).

Conclusion

The solar maximum is the best possible window available for physicists to both launch and observe the sun. Investing in indigenous technologies, international collaboration, AI-based space weather forecasting, and solar research will enhance scientific understanding, improve disaster preparedness, and ensure the sustainable and secure use of space.

3.9. OTHER ISRO RELATED DEVELOPMENTS

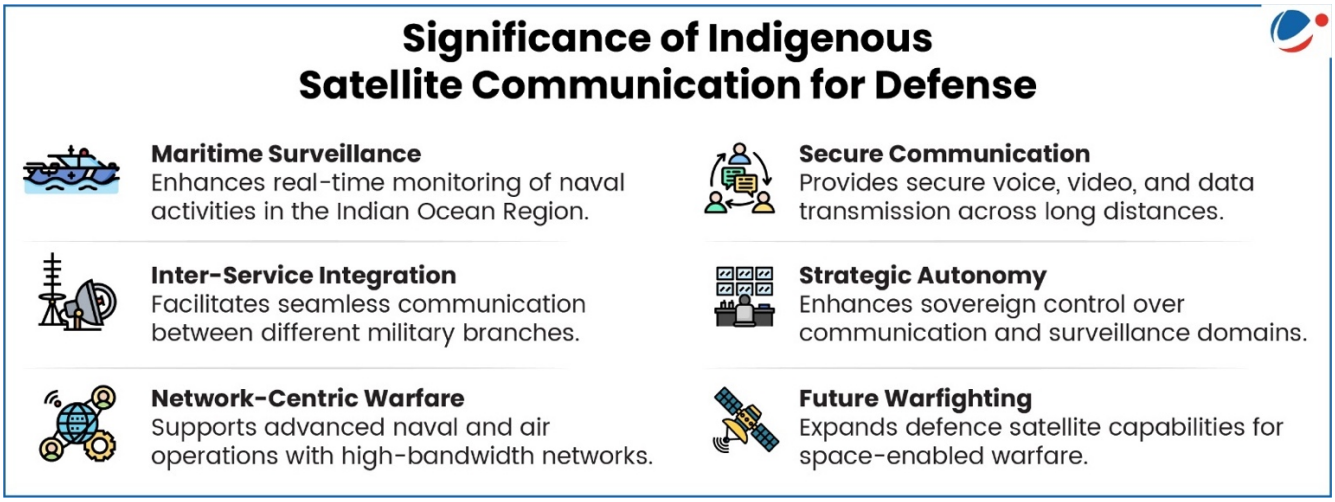
3.9.1. GSAT-7R

Why in the News?

GSAT-7R (CMS-03) Satellite was successfully launched aboard the LVM3 (India's **heaviest operational rocket**) from the Satish Dhawan Space Centre, Sriharikota.

About GSAT-7R (CMS-03) Satellite Communication

- **GSAT-7R (CMS-03)** is launched by **ISRO**.
- It is a part of India's advanced defence satellite communication **series GSAT-7.**
- **Orbit:** Launched into the Geosynchronous Transfer Orbit (GTO), it will eventually settle into Geostationary Orbit (35,786 kilometers above Earth).
- **Coverage:** Provides multi-band telecommunication services across the Indian Ocean Region and Indian landmass up to 2,000 km from India's coastline.
- **Multiple Communication channels**: The satellite operates on multiple frequency bands, which include UHF, S, C, and Ku. The system enables the transmission of voice, video and data.
- **Lifespan**: 15 years and will replace the multi-band communication satellite GSAT-7/INSAT-4F Rukmini.
- **Purpose:** Strengthens space-based communication, maritime domain awareness, and secure links among Navy ships, submarines, aircraft, and Maritime Operations Centres.
- **Other Satellites in the GSAT-7 Series**
  - **GSAT-7 (Rukmini):** Operational since 2013; provides maritime communication and surveillance.
  - **GSAT-7A (Angry Bird):** Launched in 2018; strengthens network-centric operations and data link connectivity.


Significance of Indigenous Satellite Communication for Defense
Maritime Surveillance
Enhances real-time monitoring of naval activities in the Indian Ocean Region.
Secure Communication
Provides secure voice, video, and data transmission across long distances.
Inter-Service Integration
Facilitates seamless communication between different military branches.
Strategic Autonomy
Enhances sovereign control over communication and surveillance domains.
Network-Centric Warfare
Supports advanced naval and air operations with high-bandwidth networks.
Future Warfighting
Expands defence satellite capabilities for space-enabled warfare.

Conclusion

Satellite communication has become an indispensable pillar of India's defence preparedness, enabling **secure connectivity, real-time surveillance and seamless coordination** across land, air and sea. As threats grow more complex and space becomes a critical warfighting domain, strengthening SATCOM capabilities is essential for safeguarding national security and ensuring strategic superiority.

3.9.2. LUNAR MODULE LAUNCH VEHICLE (LMLV)

Why in the News?

ISRO's heaviest rocket Lunar Module Launch Vehicle (LMLV) to be ready by 2035.

Key Features of LMLV

- **Design**: **Improved version** of the NGLV (Next Generation Launch Vehicle).
  - As tall as a **40-storey building**.
- **Purpose**: Lunar missions, including India's first human mission to the Moon planned by 2040.
- **Payload**: It can carry **80 tonnes to low Earth orbit (LEO)** or approximately **27 tonnes to the Moon**.
- **3 Stages**: **Liquid propellant for its first two stages** and a **cryogenic propellant for its third stage**.

ISRO's other Key Launch Vehicles and Capabilities

- **PSLV (Polar Satellite Launch Vehicle):** ISRO's workhorse, a third-generation vehicle, capable of launching satellites into **Sun-synchronous Polar Orbit, LEO, Geosynchronous Transfer Orbit (GTO)** (e.g., Chandrayaan-1, Mars Orbiter Mission).
- **GSLV (Geosynchronous Satellite Launch Vehicle):** A fourth-generation, three-stage vehicle designed to launch **2.0-ton class satellites into GTO** for communication satellites.
- **LVM 3:** A heavy-lift, three-stage vehicle capable of carrying **4-ton class satellites to GTO or about 10 tons to LEO** (Chandrayaan-2 and 3).
  - It is proposed to be used for **Bharatiya Antariksh Station**.
- **SSLV (Small Satellite Launch Vehicle):** Three-stage, all-solid propulsion vehicle designed for launching **Mini, Micro, or Nano satellites (10 to 500 kg mass)**.

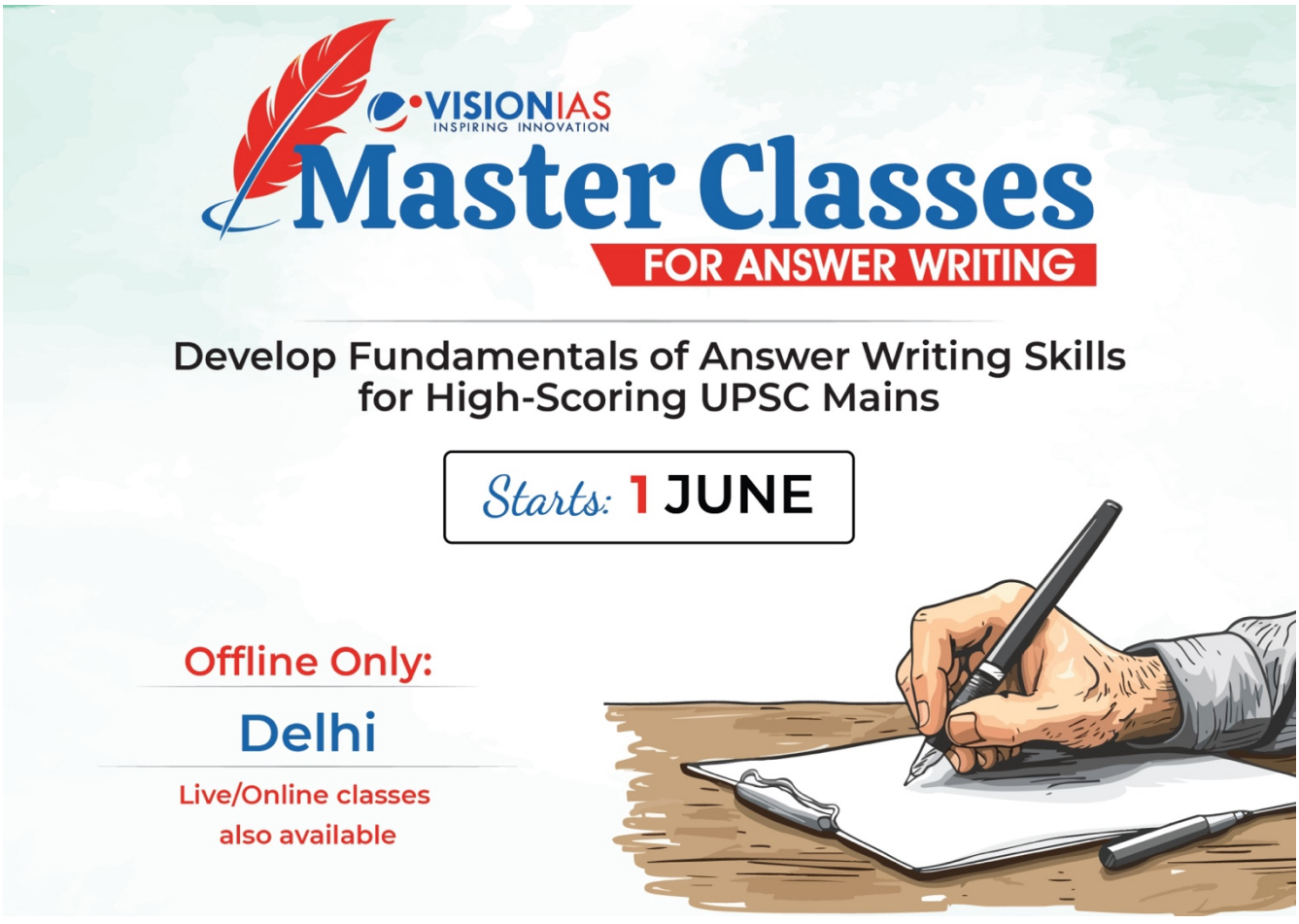
Related News

LVM3-M6 Mission

- ISRO's LVM3-M6 Mission successfully placed the Bluebird Block-2 Satellite in Low Earth Orbit (LEO).
- **About Blue Bird Block -2**
  - **Part of a global LEO constellation:** Provides **direct-to-mobile connectivity** through satellite; Enables 4G and 5G voice and video calls, texts, streaming, and data, etc.
  - **Key Features:** 223m^2 phased array, making it **largest commercial communications satellite** ever deployed into LEO.

PSLV-C62 / EOS-N1 Mission

- ISRO's PSLV-C62/EOS-N1 Mission Encountered Anomaly during 3rd Stage.
- **About PSLV-C62 / EOS-N1 Mission**
  - It includes the launch of **EOS-N1 earth observation satellite** along with **15 co-passenger satellites** from domestic & international customers.
  - It will also demonstrate **KID or Kestrel Initial Technology Demonstrator** from a Spanish startup.
    - **KID** is a **small-scale prototype** of a re-entry vehicle which after launch is slated to re-enter the earth's atmosphere towards splashdown in **South Pacific Ocean.**



3.10. PRIVATIZATION IN INDIAN SPACE SECTOR AT A GLANCE

Privatization in Indian Space Sector

India's space economy, currently valued at about **$8.4 billion (~2% global share)**, is projected to reach **$44 billion (~8% global share)** by **2033.**

Startups increased from single digit numbers in **2019** to **400+** startups by early **2026**.

Need for Promoting Private Sector in Indian Space Sector

Reducing import dependency

India's import costs in the space technology sector are **12 times** higher than the earnings from exports **(2021-22).**

Freeing up the ISRO from ancillary activities

Space entrepreneurship could free up **ISRO** to focus on the core areas of research and development.

Global Competitiveness:

Competing with global giants like **SpaceX** and **Blue Origin** requires policy support and a level playing field for India's private sector.

Socio-economic benefits

By finding innovative solutions to pressing challenges in areas such as **agriculture, disaster management, or communication.** It will also aid **employment generation.**

Initiatives taken to encourage private Sector participation in Space

Key Organizations:
It includes **IN-SPACe, Antrix Corporation Limited, New Space India Limited, Indian Space Association** for regulation, promotion, and commercialisation.

Financial Support:
It includes Venture capital fund **(SIDBI eperationalised ₹1,000 crore fund)**, Technology Adoption Fund, Seed fund scheme etc.

SpaceTech Innovation Network (SpIN):

Public-private collaboration for **start-ups** and small and **medium- enterprises** in the space industry.

Indian Space Policy 2023:
Enables end-to-end participation of **Non-Government Entities (NGEs)** in all domain of space activities.

Foreign Direct Investment (FDI):
Upto **100%** under Automatic route for Manufacturing of components and systems/ sub-systems for satellites, ground segment and user segment.

Challenges related to Privatization in Space

Absence of a Comprehensive National Space Legislation:
Without a **comprehensive legislation**, ensuring enforcement and compliance of policies is difficult, creating legal ambiguity in realization of stipulated goals.

Risky Nature of Industry:
Absence of **customized insurance products** for startups, especially in deep tech and space industries.

Limited Access to Launch Facilities:
Access to launch facilities and infrastructure, primarily controlled by government agencies like **ISRO**, can be challenging for private players.

Underdeveloped Upstream Sector
While the downstream segment (e.g., services utilizing satellites) contributes nearly **80%** of India's space economy, the upstream segment (development, testing, and launching) remains relatively underdeveloped.

Way Forward to support privatization in Space

Mapping of current value chain of the sub-segments:
Identification of challenges **(technology, business** and **adoption)**, trends and global benchmarking to define the problem for market creation.

Comprehensive Space Act:
It is essential to provide a clear **legal framework** for covering various aspects of private sector participation.

Emphasize International Financial Services Centre (IFSC) Role:
It will **Support Space Technology** and the Financial Sector, Creating Synergies for Domestic and International Space Tech Companies.

Technological Advancement:
Collaborate with the **IT sector** to leverage India's expertise in information technology for space applications.

Establish a Space Insurance Regulatory Authority:
To drive a resilient Indian space **insurance market**, fostering innovation, mitigating financial risks.

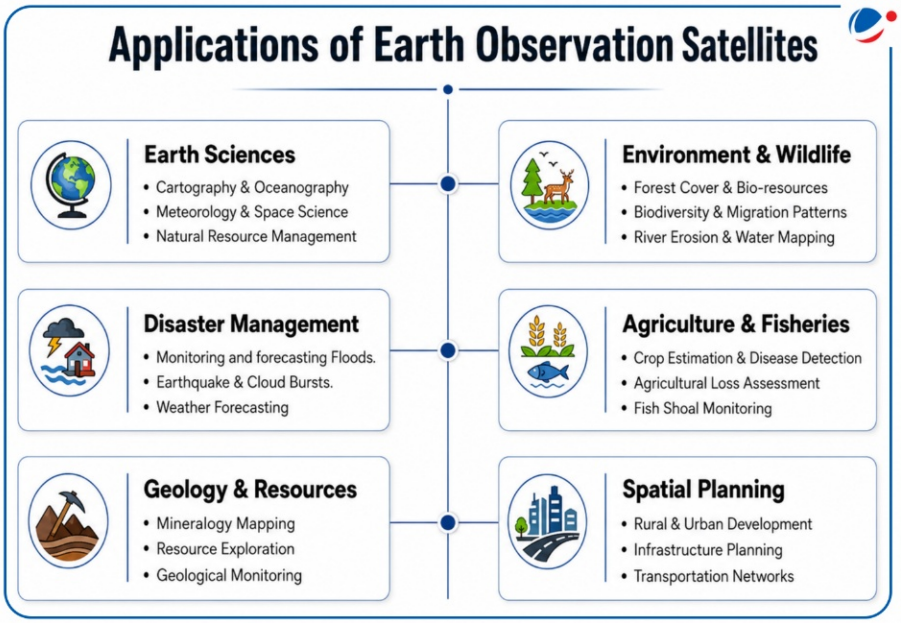
3.10.1. EARTH OBSERVATION SATELLITE SYSTEM (EOSS)

Why in the News?

PixxelSpace India-led Consortium has **won the IN-SPACe proposal to build India's first** fully indigenous commercial **Earth Observation Satellite System** (EOSS) under PPP model.

About the proposed Earth Observation Satellite System (EOSS)

- It is a **constellation of 12 state-of-the-art EO satellites** planned to be launched over the **next 5 years.**
  - **EO Satellites** are designed to collect information about activities on Earth, both natural and artificial, including physical, chemical, biological and human systems.
- It will be equipped with panchromatic, multispectral, hyperspectral, and microwave **Synthetic Aperture Radar (SAR) sensors**.



- **Significance:** Deliver **Analysis Ready Data (ARD)** and **Value-Added Services** for climate change monitoring, disaster management, agriculture, national security, serving as a source of high-quality **geospatial intelligence,** among others.

Conclusion

Going forward, sustained policy support, capacity building, and global collaborations will be crucial to ensure that India not only meets its domestic needs but also emerges as a leading exporter of space-based solutions, driving the vision of a technologically empowered and globally influential Viksit Bharat.

3.11. ENGINE TECHNOLOGY IN SPACE

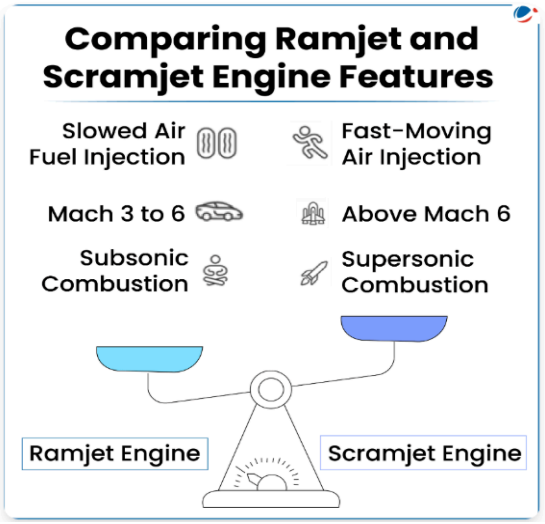
3.11.1. SCRAMJET ENGINE

Why in the News?

DRDO's Defense Research and Development Laboratory (DRDL) successfully ground-tested a full-scale, actively cooled, long-duration Scramjet engine.

More on the News

- It serves as a foundational success for the indigenous **Hypersonic Missile Development Program**.
- **India is the fourth country** to demonstrate the flight testing of a Scramjet Engine, after the US, Russia, and China.



About Scramjet (Supersonic Combustion Ramjet) Engine

- **Scramjet Engine:** It is an improvement over the ramjet engine as it efficiently **operates** at **hypersonic speeds (greater than Mach 5)** and allows **supersonic** combustion.
  - A **ramjet** is an **air-breathing jet engine** that uses the **vehicle's forward motion** to **compress incoming air** for combustion without a **rotating compressor.**
- **Fuel Used:** It generally uses hydrogen as fuel and the **Oxygen** from the atmospheric air as the oxidizer.
- **Key Features:**
  - **Depends on assisted take off:** Both ramjets and scramjets **cannot produce thrust at zero air speed**.
    - **Require another propulsion system** (like a rocket or turbojet) to reach a high enough speed to function.
  - **Uses flame stabilization technique**: This holds a continuous flame inside the combustor with an air speed in excess of 1.5 km/s.
  - **No Moving Parts:** Engine doesn't use a mechanical compressor or turbine.
  - **Increased Efficiency**: It is a more efficient propulsion system than a rocket.
    - A rocket engine carries both fuel and oxidizer.

About Hypersonic Weapons

- These are capable of speeds exceeding **Mach 5**, offering rapid global reach and high **evasion** capabilities against **air defense systems**.
- Fly at lower altitudes than **ballistic missiles**, and are highly maneuverable making them harder to track.
- **Types**:
  - **Hypersonic Glide Vehicles (HGV)**: A maneuvering weapon system that glides through the upper atmosphere at speeds exceeding Mach 5 (over 6,100 km/h) after being boosted by a rocket.
  - **Hypersonic Cruise Missiles (HCM)**: Can be fired from aircraft, much like other cruise missiles, before accelerating to hypersonic speeds. Cruise missiles are self-propelled and precision-guided weapons.
    - It maintains sustained and controlled flight to strike targets accurately.

3.11.2. CRYOGENIC ENGINES

Why in the News?

ISRO Conducted the Boot-strap mode start test on CE20 Cryogenic Engine under vacuum conditions.

About Cryogenic Engines

- **Meaning:** Last stage of space launch vehicles which makes use of Cryogenics.
- **Cryogenics** involves the study of production and behaviour of materials at extremely low temperatures (below -150 degree C).
- **Propellants Used:** Liquid Hydrogen and liquid Oxygen.
- **Significance:** More efficient and provide more thrust for every kilogram of propellant burned.
- **Earth storable** liquid and solid propellants used in liquid and solid stages are less efficient and **gives small payload advantage.**

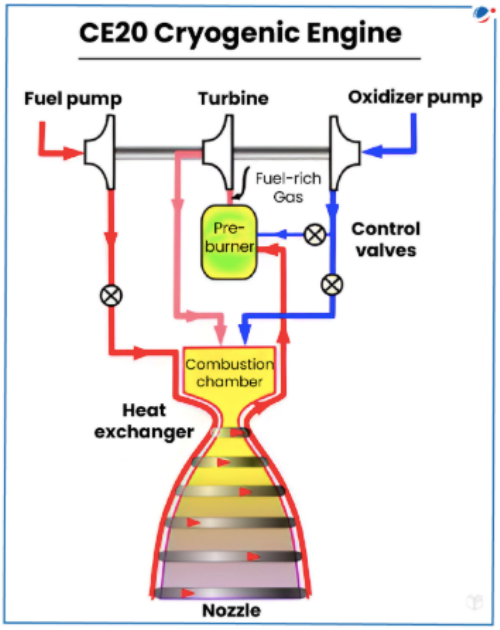
About CE20

- **Developed by**: The Liquid Propulsion Systems Centre (LPSC), Valiamala, Kerala.
- **Successful Missions:** It has demonstrated its capability by successfully operating in six successive LVM3 missions, including the Chandrayaan-2, Chandrayaan-3, and two commercial OneWeb missions.

How does a Cryogenic engine work?

- **The working principle:** The thrust is produced by an internal combustion/pressure difference.
  - **Like scramjet**, this also follows Newton's Third law of motion.

- **Fuel:** The fuel and oxidizer used in a cryogenic engine are liquefied gases, stored at extremely low temperatures.
  - Generally liquid hydrogen liquefied **at -253° Celsius** is used as fuel and liquid oxygen liquefied **at -183° Celsius** is used as oxidizer.



Advantages of cryogenic engine

- **Efficiency and Thrust:** With LOX+LH2 producing maximum energy and lightweight water vapor, resulting in higher performance.
- **Fuel Efficient:** ISRO's PSLV Vikas engine burns 3.4 kg/sec, while cryogenic engines need only 2 kg/sec for the same thrust.
- **Eco-Friendly Technology:** Hydrogen-oxygen combustion emits only steam.
- **Heavy Payloads & Space Missions**: Ideal for heavy payloads and long missions like Gaganyaan.

Challenges in Cryogenic engine technology

- **Complex Systems:** Extremely low-temperature propellants create thermal and structural issues.
- **Thermal Stress:** Risks of cracks, blockages, nozzle distortion, and stoppages.
- **High Pressure:** Requires strong superalloys to handle thrust and coolant pressures.
- **Temperature Control:** Balancing performance with coolant liner capability at low flows.

Conclusion

The CE20 Cryogenic engine marks a significant milestone in ISRO's progress with cryogenic technology.

Advancing further, ISRO could explore start fuel ampules like Tri-ethyl-aluminium and Tri-ethyl-boron to enhance ignition reliability and efficiency.

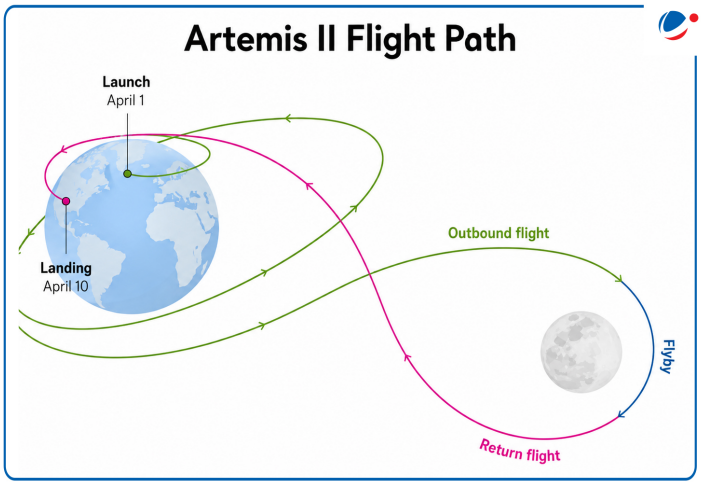
3.12. ARTEMIS II MOON MISSION

Why in the News

Artemis II astronauts returned to Earth after historic NASA mission to the Moon.

About Artemis II Moon Mission

- **Mission Type:** Crewed Lunar Flyby Mission under the NASA's Artemis Program.
- **Launch Vehicle:** Space Launch System (SLS)
- **Key Mission Objectives:**
  - **Crew:** Demonstrate the **ability of systems** and teams to sustain the flight crew in the flight environment.
  - **Systems:** Demonstrate the **systems and operations** required for a crewed lunar mission.
  - **Emergency Operations:** Demonstrate emergency system capabilities and validate associated operations.



Artemis Program

- **Mission Goals:** The Artemis program is NASA's initiative to return astronauts to the Moon, establish a permanent presence at the lunar south pole and lay the foundation for future human exploration of Mars.
- **Artemis I** successfully tested **Orion in lunar orbit (2022).**

The Artemis Accords

- **Established** in **2020** by NASA and the U.S. State Department for peaceful space cooperation.
- **It reaffirms signatories' commitment** to the Outer Space Treaty, Registration Convention, Rescue and Return Agreement and responsible norms for civil space exploration and use.
- **Member States:** 67, India is also a member.

Significance

- **Historic Milestone:** It is the first crewed mission to the Moon in 50 years since the Apollo 17 in 1972.
- **Human Safety in Deep Space:** It rigorously tests the European Space Agency Service Module and Orion life-support systems.
- **Historic Crew Representation:** The flight breaks barriers by sending the first woman **(Christina Koch),** and the first non-American astronaut **(Canadian Space Agency's Jeremy Hansen)** to the Moon's vicinity.
- **Extreme Distances:** The trajectory takes the four-person crew farther into deep space—closer to the Moon and beyond the far side—than any humans have travelled in history.
- **Geological Observations:** The crew studied and photographed lava flows and impact craters to understand the region's geological history during a three-hour flyby of the Moon's far side.
- **Astronaut Health Studies**: **ARCHeR** (to monitor astronauts' well-being, activity, and sleep), **AVATAR** (Uses organ-on-a-chip devices to study the effects of microgravity and increased radiation on the health of the crew).

Conclusion

Artemis II marks a pivotal transition from lunar exploration to long-term residence. By successfully testing crewed deep-space systems, it solidifies the foundation for a permanent South Pole base and future Martian voyages. This mission proves that international cooperation and diversity are now the driving forces of humanity's celestial expansion.

3.13. SPACE DEBRIS

Why in the News?

Solar Storms are causing Starlink Satellites to fall from the Sky.

More on the News

- Starlink has **lost 523 satellites from 2020 to 2024**, the years associated with the **peak of Solar Cycle.**
  - Solar cycle is an **approximately 11-year cycle** that tracks the rise and fall of **activity on the Sun's surface.**
- **Geomagnetic storms** caused by Sun's eruptions **increased atmospheric drag,** causing satellites to re-enter faster than expected.
  - **These lost satellites** have raised concerns about **atmospheric pollution and space Debris/Junk.**

Space Debris and Its Status

- Space debris is defined as **all non-functional, man-made objects, including fragments and elements thereof**, in Earth orbit or **re-entering into Earth's atmosphere.**
  - **Space debris objects larger than 1 cm in size** (Large enough to be capable of causing catastrophic damage) is **estimated to be over 1.2 million** (ESA Space Environment Report 2025).
- **Key Sources:** Majority of debris objects originate from **on-orbit break-ups as well as on-orbit collisions.**

- **Potential Consequences:** It can damage satellites, disrupt communication and navigation systems, and potentially endanger astronauts.

Concerns related to Space Debris

- **Threat to space exploration:** E.g., collision with a **10-cm** object would cause catastrophic fragmentation of a satellite.
- **Kessler syndrome:** Uncontrolled growth of debris can lead to self-sustained cascading collisions creating a chain of reactions.
- **Risk to life on Earth:** Large space debris that re-enter the atmosphere in an uncontrolled way can create risks for the population on the ground.
- **Rising cost of maintaining satellites in Space**: Space agencies have to undertake Collision Avoidance Manoeuvres (CAMs).

Initiatives Taken to tackle Space Debris

Global

- **Inter-Agency Debris Coordination Committee (IADC):** Established in 1993, international governmental forum for worldwide coordination related to man-made and natural debris in space.
- **UN Space Debris Mitigation Guidelines:** Prepared by UN-COPUOS and endorsed by UN General Assembly in 2007.
- **Zero Debris Charter:** Signed by 12 countries. It contains high-level guiding principles and jointly defined targets to become debris neutral by **2030.**

India

- **Debris Free Space Missions (DFSM) 2030:** To achieve debris-free space missions by all Indian space actors, by 2030.
- **ISRO System for Safe and Sustainable Operations Management (IS4OM):** Operational since 2022 to safeguard ISRO's space assets.
- **Project Network for Space Object Tracking and Analysis (NETRA**) by ISRO.

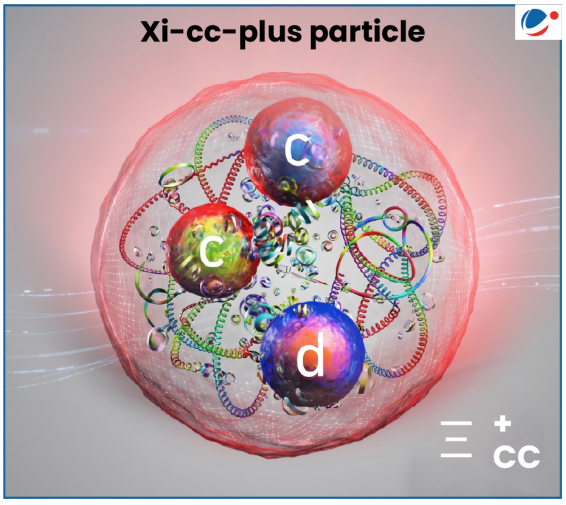
Conclusion

Ensuring the long-term sustainability of outer space requires stricter **debris-mitigation norms, safe disposal of defunct satellites, improved satellite monitoring and passivatio**n, and the deployment of Active Debris Removal (ADR) technologies through strengthened international cooperation.

3.14. LARGE HADRON COLLIDER

Why in the News?

The Large Hadron Collider (LHC) at CERN has discovered a new particle named Xi-cc-plus**,** marking its 80th particle discovery**.**



About the New Particle Xi-cc-plus

- **Structure:** It is made up of **two charm quarks** and **one down quark** similar to proton (made up of **two up quarks** and **one down quark**).
  - **Quarks** are fundamental building blocks of matter and come in six flavours (types): up, down, charm, strange, top and bottom.
- **Mass:** The replacement of **up quarks** with **charm quarks** makes its mass **four times heavier than proton.**

- **Significance of the Discovery:** It will help physicists better understand how the **strong force** binds protons, neutrons and other composite particles together.

Large Hadron Collider (LHC)

- It is the **world's largest and most powerful particle accelerator** which operates in a tunnel 100 metres underground at CERN (European Organization for Nuclear Research).
- **Structure:** It consists of a **27-kilometre ring of superconducting magnets** with a number of accelerating structures to boost the energy of the particles along the way.
- **Function:** Inside the accelerator, **two high-energy particle beams of protons or ions** travel at close to the speed of light before they are made to collide.
- **Significance:** These collisions produce particles and fields necessary for fundamental understanding of nature such as mass, dark energy and dark matter etc.
- **Other Discoveries by LHC:** Higgs Boson (2012); Exotic hadrons (Particles composed of four or five quarks); Rare B- meson decay; etc.

India's contribution in LHC

- **Partnership:** Indian scientists and institutions are represented in CERN boards and committees, including Research and Resources Board (RRB), Advisory Committee of CERN Users (ACCU) and Scientific Council.
- **Hardware for the LHC Accelerator:** Indian teams, particularly from **BARC (Mumbai) and RRCAT (Indore)**, made key contributions to the LHC by developing high-precision **cryogenic systems, superconducting magnet components, beam instrumentation, and collimators.**
- **ALICE Experiment (A Large Ion Collider Experiment):** Played pivotal leadership roles in the ALICE collaboration.
- **CMS Experiment (Compact Muon Solenoid):** Contributed towards development of software, analyses strategy from early days of CMS and, finally, physics analyses of data.
- **Worldwide LHC Computing Grid (WLCG):** It is a global network that processes and analyses the vast data generated by LHC experiments.
    - Indian Tier-2 centres, notably at **TIFR Mumbai and VECC Kolkata,** have been central to providing computing and storage resources.

CERN

- **CERN**, the European Organization for Nuclear Research, is one of the world's largest and most respected centres for scientific research situated at **Franco-Swiss border near Geneva.**
- **Founded** in 1954
- **Members:** 25 member states
    - **India** is an associate member.
- **Mission:** World-class research in fundamental physics using advanced particle accelerators

Conclusion

The discovery of Xi-cc-plus at CERN highlights the continuing success of the Large Hadron Collider in advancing fundamental physics. It deepens our understanding of quark interactions and the strong force, thereby contributing to a more comprehensive picture of the building blocks of matter and the fundamental laws governing the universe.

3.15. NEUTRINOS

Why in the News?

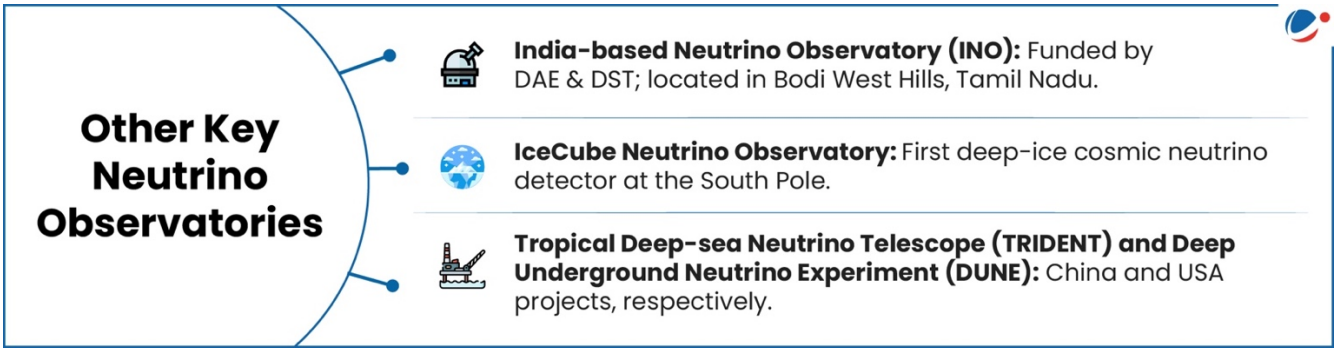
World's Largest Neutrino Detector known as the Jiangmen Underground Neutrino Observatory (JUNO), is activated in China.

About JUNO

- The observatory is situated **700 meters underground.**
  - Most of the neutrino observatories are underground, as the physical bulk of the Earth's crust helps **block most other interfering particles**, like muons (elementary subatomic particles similar to the electron).
- **Main goals of the JUNO**
  - **Mass Hierarchy:** To determine the hierarchy of masses between the three neutrino types.
    - The three neutrino types are **Electron neutrino, Muon neutrino, and Tau neutrino**, each linked to their respective particles.
  - **Oscillation Frequency:** To measure the frequency of neutrino oscillation (how often the neutrino types shift, or change, from one type to another).

About Neutrinos

- **Nature:** Subatomic particles (often called **ghost particles)** that have zero electrical charge, zero size and tiny mass.
- **Occurrence: Second-most abundant particle after photons** (particles of light) and most abundant among particles found in the universe.
- **Detectability:** Difficult to detect as they only interact with matter via **weak nuclear force and gravity.**
- **Features:** Undisturbed by even the strongest magnetic field, Travel in straight lines from their source, Travel at nearly the speed of light, etc.


Other Key Neutrino Observatories
India-based Neutrino Observatory (INO): Funded by DAE & DST; located in Bodi West Hills, Tamil Nadu.
IceCube Neutrino Observatory: First deep-ice cosmic neutrino detector at the South Pole.
Tropical Deep-sea Neutrino Telescope (TRIDENT) and Deep Underground Neutrino Experiment (DUNE): China and USA projects, respectively.

3.16. BLACK HOLE MERGER

Why in the News?

The international **LIGO-Virgo-KAGRA (LVK)** collaboration of gravitational wave observatories has recently detected the merger of two exceptionally massive black holes named **GW231123.**

Key Highlights of the Event

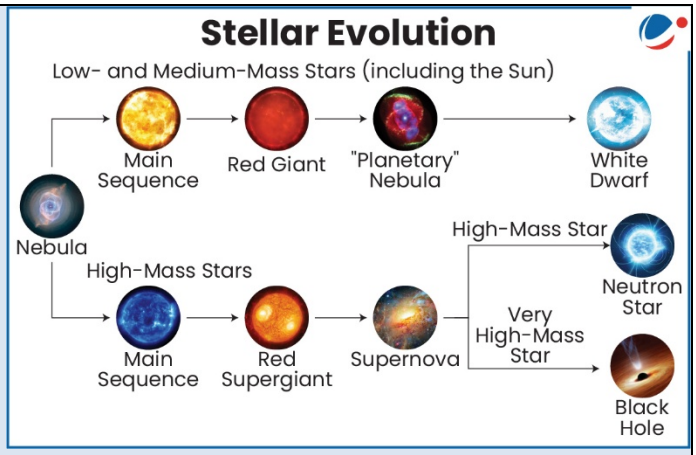
- **Event:** GW231123, occurred billions of years ago and was detected through **Gravitational Waves (GW)** from it.
- **Heaviest Merger:** Involved two black holes with masses of about 100 and 140 times the Sun merging to form a final black hole weighing ~225 solar masses.

Significance of the event

- **Refine Astrophysical and Cosmological Models:** The detection has the **potential to refine the current understanding of black hole formation, the evolution of stars,** etc.
  - It opens up **new directions in theories of gravity, astrophysics, cosmology, particle physics, or cosmic strings.**
- **Challenges the current understanding of black hole formation:** This merger surpasses all previous detections in mass, resetting our understanding of black hole extremes.
- **Insight into Hierarchical Mergers:** One proposed possibility for the formation of such massive intermediate-mass black holes (like those detected in GW231123) is through a **"hierarchy of mergers" of smaller black holes.**
- **Gravitational Waves as a New Tool:** Advancing the Study of Gravitational Waves is particularly crucial **for studying dark matter and dark energy**.

Black Holes

- A black hole is a place in space **where gravity pulls so much that even light cannot get out**. The gravity is so strong because matter has been squeezed into a tiny space.
- Black holes don't emit or reflect light, making them effectively invisible to telescopes. However, **scientists can see how the strong gravity affects the stars and gas around the black hole**.
  - Scientists can study stars to find out if they are flying around, or orbiting, a black hole.



- **Formation of Black Hole**: Most of black holes are formed from the remnants of a large star that dies in a supernova explosion.
  - When stars are especially large, the core collapses into a black hole. Otherwise, the core becomes an ultra-dense neutron star.
- **Types of Black Hole:** Stellar, super massive, intermediate and primordial.

Conclusion

Black hole mergers provide crucial insights into gravity, spacetime, and the evolution of the universe, while advancing gravitational-wave astronomy and expanding the frontiers of modern astrophysics.

3.17. LASER INTERFEROMETER GRAVITATIONAL-WAVE OBSERVATORY (LIGO)

Why in the News?

Larsen & Toubro Wins Department of Atomic Energy Contract to Build LIGO-India Facility in Hingoli district, Maharashtra.

About LIGO

- LIGO is the **world's largest gravitational-wave observatory** that detects **ripples** in space-time using laser interferometry.
- **Funded & operated by:** Supported by the **National Science Foundation** and operated by the **California Institute of Technology** and the **Massachusetts Institute of Technology**.
- **Technology:** Uses **laser interferometers with two 4-km-long arms arranged in an L-shape** to measure extremely tiny distortions in space-time.

- **Detectors:** Two main observatories located about **3000 km apart** at **Hanford (Washington)** and **Livingston (Louisiana)** in the USA.
- **Global Network:** Works with detectors such as the **Virgo detector (Italy)**, the **KAGRA (Japan)** and GEO600 (in Germany).

LIGO-India

- **InDIGO (the Indian Initiative in Gravitational-wave Observations):** An initiative to set up advanced experimental facilities for a multi-institutional Indian national project in gravitational-wave astronomy.
- **Nature:** LIGO-India is a planned gravitational-wave observatory that will be part of the global network of detectors.
- **Implemented by:** the Department of Atomic Energy (DAE) and the **Department of Science and Technology (DST)** in collaboration with the **National Science Foundation (USA).**
- **Objective:** Improve the **detection accuracy and 59ocalization of gravitational-wave sources** across the sky through a globally distributed detector network.

What are gravitational waves?

- **Gravitational waves** are 'ripples' in space-time caused by some of the most violent and energetic processes in the Universe.
- **Predicted** by Albert Einstein in **1916** as a consequence of his general theory of relativity.
- They travel at the **speed of light** (Nearly 186,000 miles per second).
- These waves **squeeze and stretch anything** in their path as they pass by.
- **Some examples of events** that could cause a detectable gravitational wave are:
  - When a **star explodes asymmetrically** (called a supernova)
  - When **two big stars orbit each other.**
  - When two **black holes orbit each other and merge.**
  - When **two neutron stars collide**. (GW170817 wave detected in 2017 by LIGO detectors)

Conclusion

LIGO has opened a new era in astronomy by enabling the detection of gravitational waves, validating Einstein's predictions, and deepening our understanding of the universe. With initiatives like LIGO-India, it will further advance scientific discovery, technological innovation, and global collaboration in frontier research.

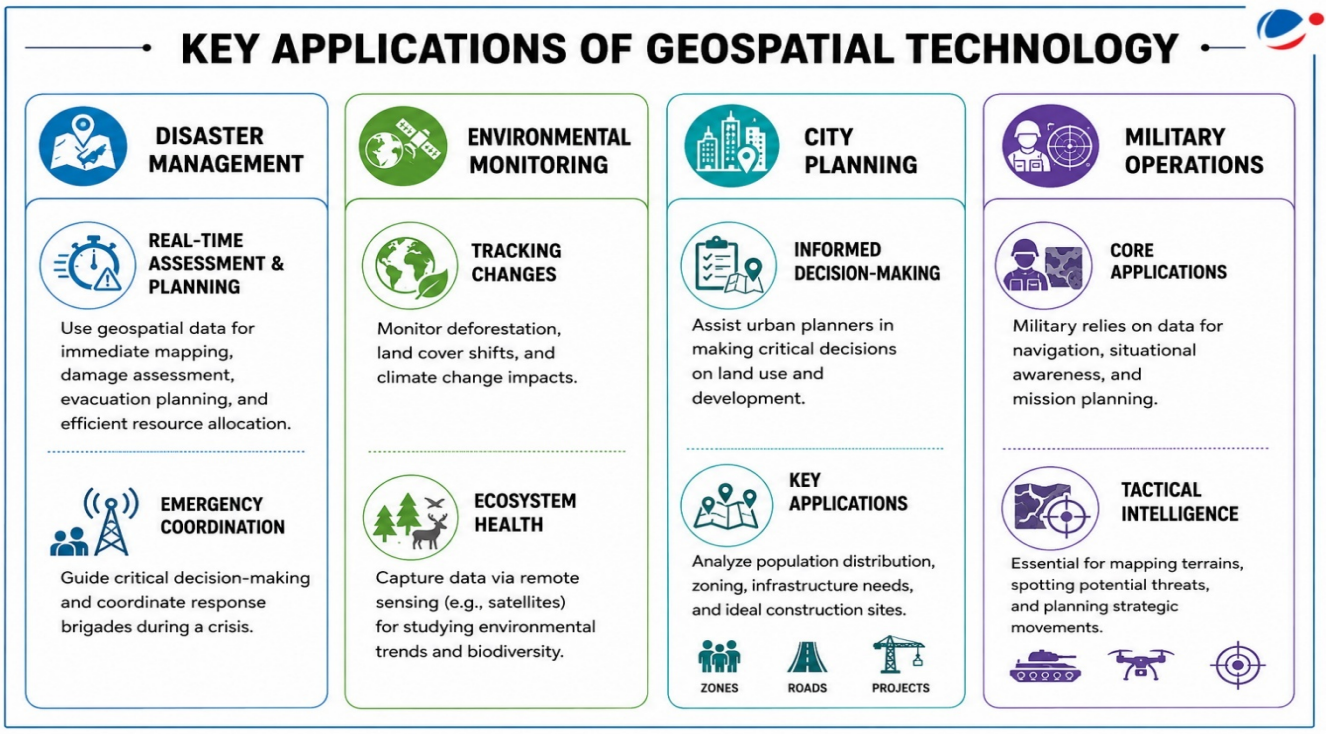
3.18. GEOSPATIAL TECHNOLOGY

Why in News?

At GeodCon-26, the first National Conference on Geodesy, held in New Delhi, **National Geospatial Policy 2022** was highlighted as a landmark reform that liberalised the **Geospatial Technology** sector.

About Geospatial Technology

- It is a **collective term** for tools that help us to collect data for understanding geographic areas and monitor changes or patterns in landscapes, cities and even societies.
- **Key Geospatial technologies**:
  - **Remote Sensing**: Acquiring information from a distance using satellites, drones, or aircraft to collect imagery and sensor data.
  - **Geographic Information Systems:** Frameworks for capturing, managing, and analyzing spatial data to reveal patterns and relationships.
  - **Global Positioning System:** Satellite-based navigation systems providing precise location and time data for mapping and tracking.


KEY APPLICATIONS OF GEOSPATIAL TECHNOLOGY
DISASTER MANAGEMENT
REAL-TIME ASSESSMENT & PLANNING
Use geospatial data for immediate mapping, damage assessment, evacuation planning, and efficient resource allocation.
EMERGENCY COORDINATION
Guide critical decision-making and coordinate response brigades during a crisis.
ENVIRONMENTAL MONITORING
TRACKING CHANGES
Monitor deforestation, land cover shifts, and climate change impacts.
ECOSYSTEM HEALTH
Capture data via remote sensing (e.g., satellites) for studying environmental trends and biodiversity.
CITY PLANNING
INFORMED DECISION-MAKING
Assist urban planners in making critical decisions on land use and development.
KEY APPLICATIONS
Analyze population distribution, zoning, infrastructure needs, and ideal construction sites.
ZONES
ROADS
PROJECTS
MILITARY OPERATIONS
CORE APPLICATIONS
Military relies on data for navigation, situational awareness, and mission planning.
TACTICAL INTELLIGENCE
Essential for mapping terrains, spotting potential threats, and planning strategic movements.

About India's National Geospatial Policy 2022

- **Vision:** Position India as global leader in geospatial sector, develop national framework, and enable easy availability of valuable geospatial data.
- **Institutional Framework:**
  - **Geospatial Data Promotion and Development Committee (GDPDC)** as apex body for promotion of geospatial sector.
  - **Survey of India** as overarching nodal agency for geospatial data

Challenges related to Geospatial Technology sector

- **Cyber espionage**: Disclosure of classified information concerning military installations or critical infrastructure carry significant consequences for security.
- **Low Awareness and Adoption**: **E.g.,** Local Panchayats rarely use GIS for resource management.
- **High Cost**: E.g., LiDAR, drones, and high-resolution satellites are expensive,
- **Lack of Indigenous software and hardware technology:** India is largely reliant on imports for geospatial equipment and software, raising concerns regarding financial viability and data sovereignty.
- **Shortage of skilled personnel:** India faces a scarcity of trained professionals equipped to handle all facets of the geospatial domain.

Recent Government Initiatives for Geospatial Technology in India

- **Operation Dronagiri:** Aims to demonstrate the real-world applications (in sectors such as agriculture, infrastructure) of geospatial technologies.
- **National Geospatial Mission:** Announced in Union Budget **2025–26**, it aims to develop foundational geospatial infrastructure and data, playing a crucial role in modernizing land records, urban planning, and infrastructure design.
- **Pan-India Continuously Operating Reference Stations (CORS): I**t is a **Network** to enhance geospatial infrastructure, ensuring high-accuracy location data.
- **National Geospatial Data Repository:** A centralized platform for geospatial data management and access.
- **Other:** National Geo-Spatial Platform, etc.

Conclusion

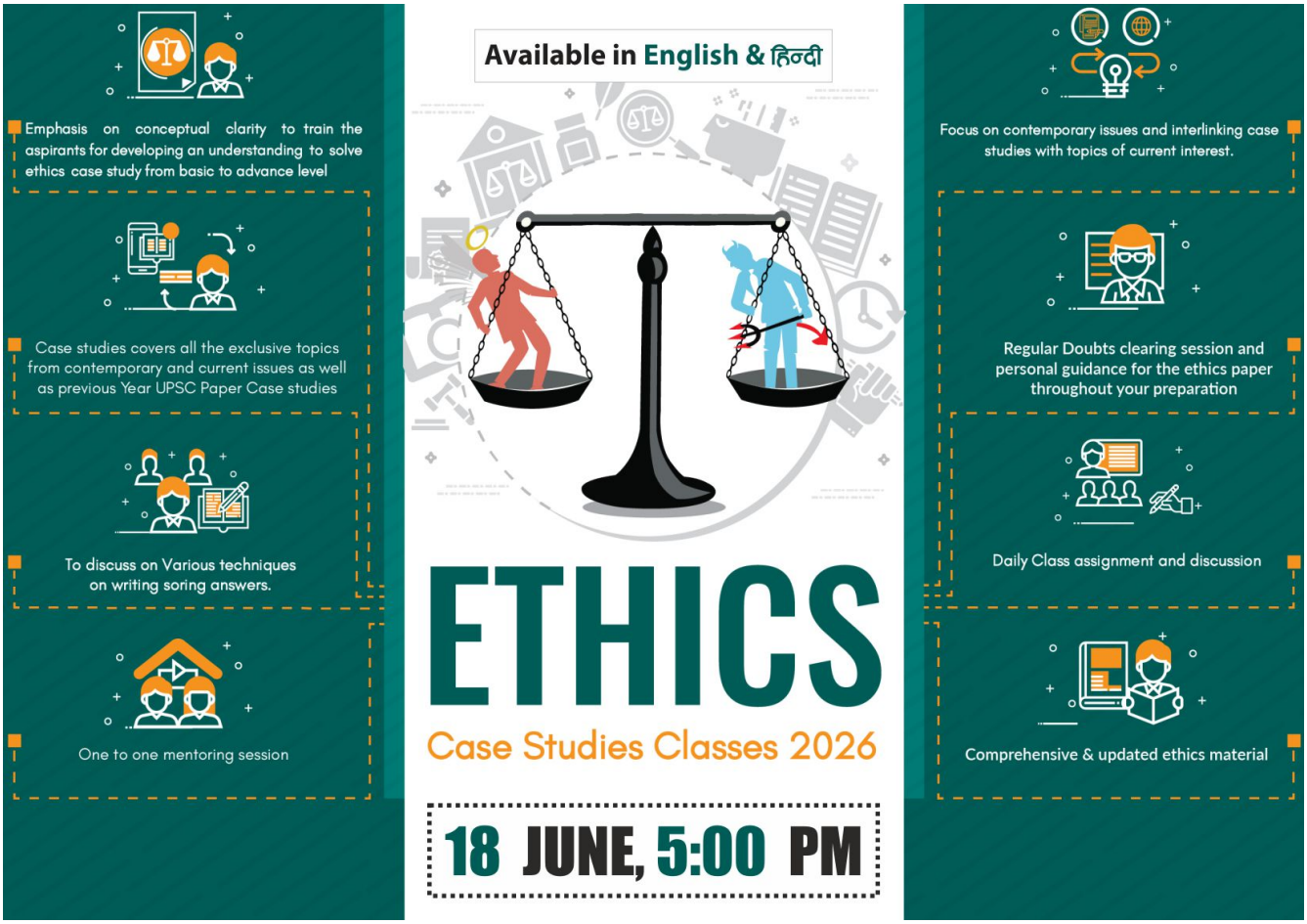
Geospatial technology is poised to transform governance and economic planning in India. The National Geospatial Policy 2022 provides a strong foundation through liberalisation and data accessibility. Going forward, addressing security, privacy, skill gaps, and technological dependence will be crucial to fully realise its potential and position India as a global geospatial leader.

3.19. KEY WORDS

Keywords			
NISAR	**NavIC**	**Astrosat**	**Gaganyaan**
Artemis II	**HOPE Mission**	**Neutrinos**	**Aditya-L1 Mission**
Large Hadron Collider (LHC)	**Black Holes**	**LIGO**	**Space Debris**

3.20. PRACTICE QUESTION

Discuss the significance of the Axiom-4 Mission for India's space programme and the challenges associated with commercial human spaceflight.			
Introduction	**Body Part 1**	**Body Part 2**	**Conclusion**
Briefly write about Axiom-4 Mission	Significance of Axiom-4 Mission for India	Challenges in Commercial Human Spaceflight.	Way forward + future of India's space ambitions.


Emphasis on conceptual clarity to train the aspirants for developing an understanding to solve ethics case study from basic to advance level
Case studies covers all the exclusive topics from contemporary and current issues as well as previous Year UPSC Paper Case studies
To discuss on Various techniques on writing soring answers.
One to one mentoring session
Available in English & हिन्दी
ETHICS
Case Studies Classes 2026
18 JUNE, 5:00 PM
Focus on contemporary issues and interlinking case studies with topics of current interest.
Regular Doubts clearing session and personal guidance for the ethics paper throughout your preparation
Daily Class assignment and discussion
Comprehensive & updated ethics material

4. HEALTH

4.1. ANTIMICROBIAL RESISTANCE (AMR)

Why in the News?

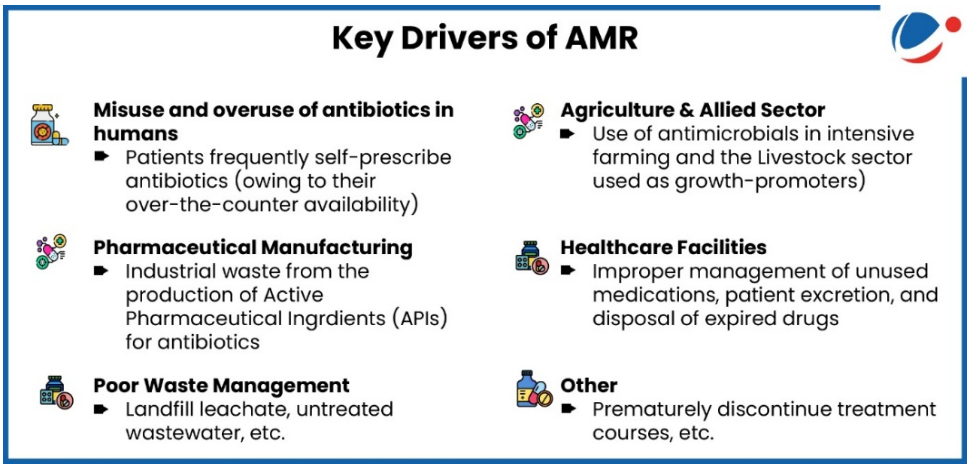
World Health Organization (WHO) released the **Global Antibiotic Resistance Surveillance Report 2025**.

Key Findings of the Report

- **Antibiotic Resistance:** In 2023, approximately **1 in 6 bacterial** infections worldwide was caused by **antibiotic-resistant bacteria**.
- **India Related Finding**: Around 41% of bloodstream infection reports came from China, India, and Pakistan combined.

What is meant by Antimicrobial Resistance (AMR)?

- **AMR** occurs when **bacteria**, **viruses**, **fungi,** and **parasites** evolve to **withstand** the **drugs designed** to **kill them**.
  - Strains of bacteria, viruses, parasites, and fungi that are resistant to most **antimicrobials** are called **Superbugs.**
- **AMR** is a **natural process** that happens over time through **genetic changes** in **pathogens**.
  - **However,** its emergence and spread are accelerated due to several anthropogenic factors.
- **WHO recognized AMR** as one of the **top ten global health threats**.


Key Drivers of AMR
Misuse and overuse of antibiotics in humans
Patients frequently self-prescribe antibiotics (owing to their over-the-counter availability)
Agriculture & Allied Sector
Use of antimicrobials in intensive farming and the Livestock sector used as growth-promoters)
Pharmaceutical Manufacturing
Industrial waste from the production of Active Pharmaceutical Ingrdients (APIs) for antibiotics
Healthcare Facilities
Improper management of unused medications, patient excretion, and disposal of expired drugs
Poor Waste Management
Landfill leachate, untreated wastewater, etc.
Other
Prematurely discontinue treatment courses, etc.

Why is AMR a Global Health Threat?

- **Mortality and Morbidity:** Bacterial AMR was directly responsible for **1.27 million** deaths in 2019 and contributed to **nearly five million** deaths globally.
- **Economic Impact**: Resistant infections could cause an estimated **$3 trillion** in global GDP losses per year by **2030.**
- **Outpacing advances in modern medicine**: It makes infections increasingly difficult to treat and renders medical procedures such as surgery far riskier.
- **Threat to Food Security**: Drug-resistant infections impact the health of animals and plants, reducing productivity in farms.
- **Spread of resistance genes:** Creating a "**Silent Pandemic**", expected to cause over **39 million** deaths globally between 2025 and 2050.

Measures taken to address AMR

National

- **National Program on AMR containment**: Launched to carry out surveillance of antimicrobial usage in healthcare settings.
- **Drugs and Cosmetics Rules, 1945**: Antibiotics included in **Schedule H1** of the rules are required to be sold by retail only under the prescription of a **Registered Medical Practitioner**.

- **Red Line awareness campaign**: Urging people not to **use medicines marked** with a red vertical line, including antibiotics, without a doctor's prescription.
- **National Action Plan on Antimicrobial Resistance 2.0 (2025-29):** Aims to prevent emergence and transmission of AMR through **Multisectoral evidence**-based **'One Health'** approach**.**

Global

- **Global Action Plan (GAP), 2015:** Adopted by the World Health Assembly of WHO.
- **Quadripartite Joint Secretariat on AMR:** It includes **WHO, Food and Agriculture Organization (FAO)**, the **UN Environment Programme (UNEP),** and the **World Organisation for Animal Health (WOAH)**.
- **United Nations General Assembly Political Declaration on AMR (2024)**: It aims to reduce deaths associated with **bacterial AMR** by at least 10%.
- **WHO AWaRe (Access, Watch, Reserve)**: It is **antibiotic book provides** concise, **evidence-based** guidance on the choice of antibiotic, dose, route of administration, and duration of treatment.
  - **Access antibiotics** that have a narrow spectrum of activity and a **good safety profile** in terms of side-effects.
  - **Watch antibiotics** that are broader-spectrum antibiotics and are recommended as **first-choice options**.
  - **Reserve antibiotics** that are last-choice antibiotics used to treat **multi-drug-resistant** infections.

Way Forward

- **Integrated intervention**: Includes infection prevention and control, **WASH** (Water, Sanitation and Hygiene), vaccination, antimicrobial stewardship, and strengthened laboratory systems.
  - **Antimicrobial stewardship** promotes evidence-based and judicious use of antimicrobials by healthcare professionals.
- **Strict implementations of Drugs and Cosmetics Rules, 1945:** All pharmacist associations shall adhere to the rules and sell antibiotics only with valid prescriptions.
- **Enhancing Monitoring**: Generating **reliable surveillance data**, especially from underserved areas.
- **Appropriate Antibiotic selection**: Reduce use of AWaRe Watch antibiotics and increase the use of Access antibiotics
- **Other**: Enforce stricter controls on antibiotic use in Agriculture and Veterinary, expand social protection, such as Universal health coverage (UHC).

Conclusion

AMR is a growing threat to health, food security, and sustainable development. Addressing it requires a One Health approach, strengthened surveillance, rational antibiotic use, and global cooperation to preserve antimicrobial effectiveness for future generations.

4.2. NON-COMMUNICABLE DISEASES

Why in the News?

India's Disease Burden has been shifted to Non-Communicable Diseases (NCDs) according to Global Burden of Disease (GBD) Report.

Findings of the report:

- **Shift toward NCDs:** According to report, **NCDs** accounted for **nearly two-thirds of global DALYs (Disability-Adjusted Life Years) in 2023**.
- **Leading NCD Causes**: The leading Level 3 NCDs globally were **ischaemic heart disease, stroke and diabetes.**

What are Non-Communicable Diseases?

- **NCDs** also known as chronic diseases, tend to be of long duration and are the result of a combination of genetic, physiological, environmental and behavioural factors.

- **The main types of NCDs** are cardiovascular diseases (such as heart attacks and stroke), cancers, chronic respiratory diseases and diabetes.

Causes of the Rising Burden of Non-communicable Diseases

- **Epidemiological & Demographic Transition:** India is **shifting from communicable to lifestyle-related chronic diseases** due to urbanization, aging population**.**
- **Lifestyle Factors:** Rapid adoption of **processed diets, sedentary life styles** (e.g. due to quick delivery apps), and increasing tobacco and alcohol use has significantly raised the risk of cardiovascular diseases**.**
- **Environmental Risk Factors:**PM2.5 exposure from industry, fossil fuels, and biomass burning causes chronic respiratory and cardiovascular diseases **E.g. Cities like Delhi.**
- **Biological Risk Factors**: Rising obesity, hypertension, hereditary predisposition increase vulnerability to NCDs
- **Psychosocial and Mental Health Factors:** Stress, urban pressures, job insecurity, and social isolation indirectly worsen NCD risks by promoting unhealthy coping behaviors **E.g. FOMO Culture (Social media).**

Impact of Non-communicable Diseases on India

- **Leading Cause of Death**: NCDs account for **63–65% of all deaths in India (2023),** with cardiovascular diseases, cancers, chronic respiratory illnesses, and diabetes as major contributors**.**
- **Premature Mortality**: NCDs contribute significantly to deaths occurring between **ages 30–70.**
- **Morbidity & Disability:** NCDs **cause long-term illness, disability, and dependence**, affecting quality of life across urban and rural areas and all socioeconomic groups.
- **Strain on Health System**: Rising NCD burden increases demand for **diagnostic infrastructure, medicines, chronic care, and diverts public expenditure** from other development priorities.
- **Socioeconomic & Developmental Challenges:** NCDs undermine SDG **progress,** including health equity, poverty reduction, and gender equality.

Initiatives taken to Control NCD

- **National Program for Prevention and Control of NCDs (NP-NCD):** Strengthens healthcare infrastructure, trains personnel, ensures early diagnosis, and spreads awareness.
- **National Program for Prevention and Control of Cancer, Diabetes, Cardiovascular Diseases, and Stroke (NPCDCS)**: Launched in 2010 to combat NCDs.
- **Health Infrastructure:** District NCD Clinics, Day Care Centers, Cardiac Care Units, and CHC NCD Clinics improve treatment access.
- **National Tobacco Control Program (NTCP):** Launched **in 2007-08** for creating awareness about the harmful effects of tobacco consumption; reducing production, etc.
- **United Nations General Assembly (UNGA) Declaration on Non-Communicable Diseases and Mental Health:** Expanded Scope to New NCDs areas included like oral health, lung health, childhood cancer, etc.

Way Forward to Control NCD

- **Health Promotion:** Encouraging healthy lifestyles through **awareness, diet, exercise, tobacco cessation, and reduced alcohol use.**
- **Early Detection:** Screening **adults 30+** for diabetes, hypertension, and cancers to ensure timely care.
- **Healthcare Strengthening**: Expanding **NCD clinics, critical care**, referral services, and training healthcare workers for better management.
- **Digital Health:** Using teleconsultation, digital portals, and data systems for monitoring, decision-making, and remote specialist access, leveraging **the National Digital Health Mission.**
- **Leveraging fiscal tools:** To reduce risk factors e.g. raising taxes on tobacco, Salt, sugar etc.
- **Sustainable Financing**: Ensuring regular medicines, diagnostics, and funding, aligned with **SDG 3.4** to cut **premature NCD deaths by one-third by 2030.**

Conclusion

With NCDs accounting for the largest share of the global disease burden, integrated action across health, nutrition, urban planning, education, and environmental sectors is essential to build a healthier and more productive future.

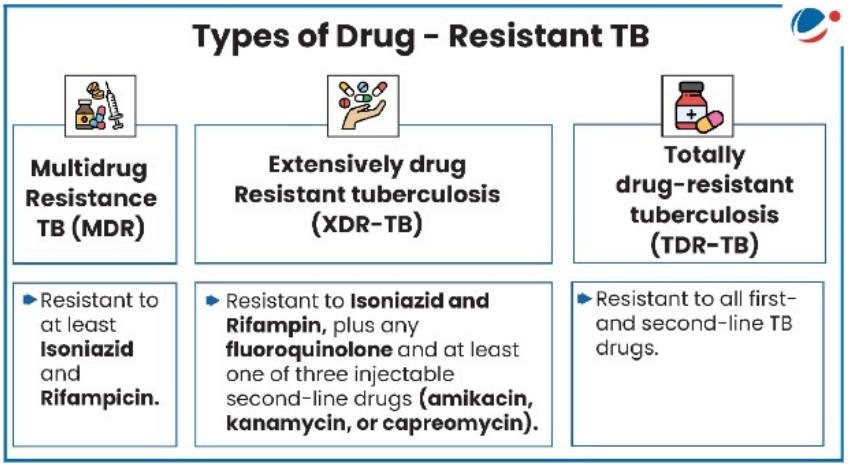
4.3. TUBERCULOSIS (TB)

Why in the News?

According to WHO Global TB Report 2025**,** India's TB incidence (new cases emerging each year) reduced by 21%.

More on the News

- The report highlights **TB is among top 10 causes** of death worldwide and leading cause of death from a single infectious agent.
- **Other key findings**
  - **Global: 1**.23 million died from the TB **in 2024**.
  - **India:** TB mortality rate has **decreased from 28 per lakh population in 2015 to 21** per lakh population in **2024.**
    - > **Global TB Burden** is highest in India (**25% TB patients**).


Types of Drug - Resistant TB
Multidrug Resistance TB (MDR)
Resistant to at least Isoniazid and Rifampicin.
Extensively drug Resistant tuberculosis (XDR-TB)
Resistant to Isoniazid and Rifampin, plus any fluoroquinolone and at least one of three injectable second-line drugs (amikacin, kanamycin, or capreomycin).
Totally drug-resistant tuberculosis (TDR-TB)
Resistant to all first- and second-line TB drugs.

About Tuberculosis (TB)

- It is a **contagious airborne disease** caused by a bacterium called **Mycobacterium tuberculosis**. It is preventable and curable.
- **Types based on site of Infection:**
  - **Pulmonary TB**: Most common form affecting the lungs, and is contagious spreading through airborne droplets through coughing or sneezing.
  - **Extrapulmonary TB**: Occurs outside the lungs, affecting organs like lymph nodes, bones, brain, kidneys, or the pleura, less contagious and spreads within the body from lungs.
  - **Spinal TB (Pott's disease):** Affects the spine and can cause severe back pain and mobility issues.

Factors leading to TB Control in India

- **Key Government Initiatives**:
  - **National TB Elimination Program (NTEP):** Revised National Tuberculosis Control Programme (RNTCP) renamed as NTEP in 2020 aims to eliminate TB in India by 2025.
  - **National Strategic Plan (2017-25)** for Ending TB in the country by 2025.
  - **Pradhan Mantri TB Mukt Bharat Abhiyaan (PMTBMBA):** Launched in 2022, with the objectives to provide additional support to TB patients.
  - **Nikshay Poshan Yojana** (NPY): Launched in 2018 by the Ministry of Health and Family Welfare, provides financial assistance of ₹1,000/- per month to each notified tuberculosis (TB) patient for nutritional support.
- **Addressing Infrastructure Gaps:**
  - **Strengthening Public Health Infrastructure**: Expansion of TB diagnostic centres, microscopy labs and treatment centres under NTEP.
  - **Digital Health & Monitoring Systems**: Launch of **Nikshay Portal**, web-based patient management and surveillance system under NTEP.

- **Introduction of Newer Therapies**: New treatment regimens like **BPaLM** (Bedaquiline + Pretomanid + Linezolid + Moxifloxacin) have transformed TB care, especially for drug-resistant TB.
- **Better Diagnosis: Universal Drug Susceptibility Testing (UDST)** implemented under the NTEP to ensure every diagnosed TB patient is tested to rule out drug resistance.
- **Harnessing Advanced Technologies**: The use of a**rtificial intelligence (AI) and Molecular diagnostic technologies** (nucleic acid amplification test (NAAT) and whole-genome sequencing (WGS)) has strengthened early detection and monitoring of TB cases.

Challenges persist in Eradicating TB in India

- **Gaps in Diagnosis**: Rural regions often lack advanced diagnostic facilities. **E.g.,** Active case findings of 250 from 1250 individuals in Gurez valley of Kashmir.
- **Socio-Economic Disparities**: TB disproportionately affects the poor, migrants, tribal populations, and slum dwellers; over 60% of Delhi's migrant workers live in precarious conditions.
- **Looming Malnutrition**: As per a study Starvation related malnutrition has been demonstrated to increase the incidence of TB by **six to eight** times.
- **High MDR-/RR-TB Case Burden**: E.g. India accounted for more than **32%** of the global number of people estimated to have developed **MDR/rifampicin-resistant (RR)-TB** in 2024.
- **Frequent Drug Shortages**: E.g. In 2023, Maharashtra reportedly received only 25,000 tablets of Cycloserine in a month when its requirement was around three lakh tablets.
- **Implementation Challenges:** High prevalence of co-morbidities such as diabetes, recurring natural disasters, and a large unregulated private healthcare sector hinder disease control efforts.

Conclusion

TB elimination requires a sustained, multi-sectoral approach combining strong healthcare systems, uninterrupted treatment, nutrition support, community awareness, and technology-driven interventions to achieve a TB-free India.

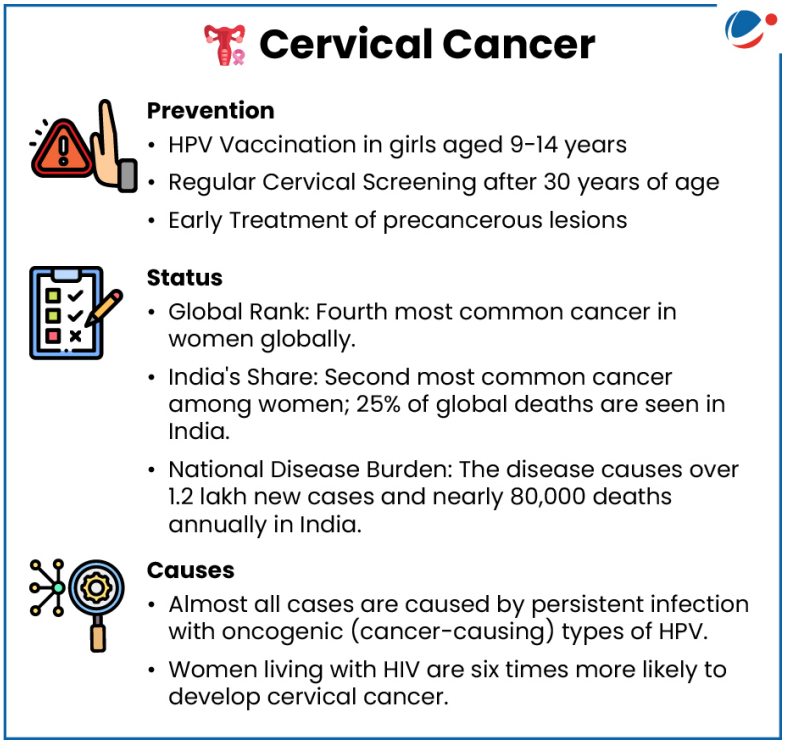
4.4. HUMAN PAPILLOMAVIRUS (HPV)

Why in the news?

Prime Minister launched a nationwide Human Papillomavirus (HPV) vaccination campaign to administer free vaccines to approximately 1.15 crore 14-year-old girls.

About Human Papillomavirus (HPV)

- **Nature:** HPV is a common **sexually transmitted infection** which can affect the skin, genital area and throat, responsible for causing genital warts, and penile, anal, cervical, vagina and oropharyngeal cancers.
- **Type:** HPV is a group of nearly 200 related viruses, of which at least 14 are cancer-causing. High-risk strains HPV-16 and HPV-18 account for about 70% of cervical cancer cases globally and over 80% in India.
- **HPV Vaccines**
  - **Cervical cancer** is the **only cancer** preventable by a vaccine.
  - **India's national program** relies on **Gardasil-4**, a quadrivalent vaccine targeting types 6, 11, 16, and 18.


Cervical Cancer
Prevention
• HPV Vaccination in girls aged 9-14 years
• Regular Cervical Screening after 30 years of age
• Early Treatment of precancerous lesions
Status
• Global Rank: Fourth most common cancer in women globally.
• India's Share: Second most common cancer among women; 25% of global deaths are seen in India.
• National Disease Burden: The disease causes over 1.2 lakh new cases and nearly 80,000 deaths annually in India.
Causes
• Almost all cases are caused by persistent infection with oncogenic (cancer-causing) types of HPV.
• Women living with HIV are six times more likely to develop cervical cancer.

- **India** has also indigenously developed **Cervavac**, manufactured by the Serum Institute of India (SII),

Initiatives for HPV Vaccine and Cervical Cancer Prevention

- **Global Initiatives**
  - **Cervical Cancer Elimination Initiative (by World Health Organization):** WHO has outlined the '90-70-90' targets for each country by 2030
    - **Vaccination**: 90% of girls fully vaccinated with the HPV vaccine by the age of 15.
    - **Screening**: 70% of women screened by the age of 35, and again by the age of 45.
    - **Treatment**: 90% of women with pre-cancer treated and 90% of women with invasive cancer managed.
  - **World Cervical Cancer Elimination Day**: Observed annually on **November 17** to build awareness, track progress, and strengthen global collaboration on HPV vaccination, screening, and treatment.
- **Initiatives in India**
  - **Digital Infrastructure Integration**: The vaccination drive is supported by digital tools like **U-WIN platform** for registration of beneficiaries register and **eVIN (Electronic Vaccine Intelligence Network)** portal for tracking vaccine stocks.
  - **Partnership with GAVI**: In 2023, the Indian government established a three-year partnership with Gavi, securing **US$ 250 million in funding**.

About HPV Vaccination Drive (2026)

- **Target group**: 14-year-old girls (approx. 1.2 crore annual cohort).
- **Nature**: Vaccination is voluntary, provided free of cost, and requires mandatory parental consent.
- **Rollout plan**: The intensive campaign runs for **90 days**, after which the vaccine will be available on routine immunization days.
  - **Shots a**re administered only at designated Government Health Facilities.
- **Vaccines used**: A **single dose (0.5 ml) of Gardasil-4** administered intramuscularly.

Conclusion

With over 500 million doses administered globally, HPV vaccines are **highly effective (93–100%) in** preventing cervical cancers caused by targeted HPV strains. Expanding HPV vaccination advances the vision of **"Swasth Nari, Sashakt Parivar**" by promoting prevention, protection, and equity in women's healthcare.

4.5. NATIONAL ONE HEALTH MISSION

Why in the News?

Government to launch National One Health Mission (NOHM).

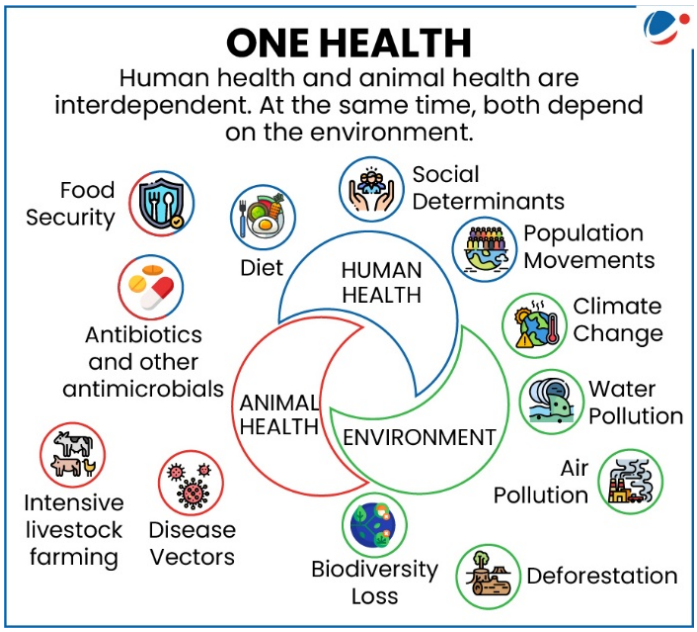
About National One Health Mission

- **A multi-sectorial initiative** integrating **human, livestock, wildlife and environmental** health to strengthen coordinated surveillance, diagnostics and outbreak response.
  - **'One Health Approach** is an integrated, unifying approach that aims to sustainably balance and optimize the health of people, animals, and ecosystems.
- **Vision:** To build an **integrated disease control** and pandemic preparedness system in India by bringing human, animal and environmental sectors together for better health outcomes.
- **Approved by**: Prime Minister's Science, Technology, and Innovation Advisory Council (PM-STIAC) in **2022.**
- **Anchor Institution:** National Institute of One Health, Nagpur.

Key Pillars of One Health Mission

- **Research and Development:** Driving targeted R&D to develop essential tools such as vaccines, diagnostics, and therapeutics.
- **Clinical Readiness:** Enhancing preparedness in terms of clinical care infrastructure and response capabilities.

- **Data Integration:** Streamlining data and information linkages across the human, animal, and environmental sectors for improved access and analytics.
- **Community Engagement:** Ensuring close community participation to maintain a constant state of response readiness.



Need of the Mission

- **Zoonotic Risk Mitigation:** It responds to the global evidence that nearly **60% of emerging infectious diseases** are zoonotic in origin.
- **Pandemic Preparedness:** Establishes predictive **and preventive health-security architecture**, shifting India from a **reactive response model to an anticipatory**, systems-based public-health framework.
- **Rise of Antimicrobial Resistance (AMR):** Misuse of antibiotics in humans, livestock, and aquaculture is accelerating drug resistance.
- **Climate Change Impacts:** Changing climate patterns are expanding the range of vectors like mosquitoes, increasing diseases such as dengue and malaria.
- **Ecosystem Health:** Strengthens wildlife disease surveillance and biodiversity monitoring, reinforcing ecological security.

Initiatives related to one-health approach

- **Centre for One Health (CoH) at NCDC:** Coordinates efforts, runs programs (Rabies, Zoonoses, Leptospirosis, Snakebite), and promotes the One Health approach in India.
- **One Health Supporting Unit within Department of Animal Husbandry & Dairying:** Specialized team of experts established to implement the national One Health framework in India.
- **BSL-3/4 Lab Network:** A national network of high-security labs for rapid analysis of disease outbreaks across sectors.
- **Indian Council of Medical Research (ICMR)** has rolled out an AI-enabled pathogen surveillance tool under the NOHM.
- **One Health Joint Plan of Action (OH JPA**): Collaborative framework for 2022–2026 created by the Quadripartite alliance (FAO, UNEP, WHO), and WOAH) to promote one health approach globally.

Way Forward

- **Legal Mandate:** Establish a **statutory** or formally notified **inter-sectorial coordination authority** to institutionalize convergence across human, animal and environmental health domains.
- **Capacity Building:** Strengthen technical and operational capacity through training in veterinary epidemiology, wildlife surveillance, genomics, and field diagnostics.
- **State-Level Strengthening:** Set up **State One Health Cells** with dedicated financial resources, trained manpower, and technological support to ensure decentralized implementation.
- **Improved Diagnostics & Technology**: Develop a unified National One Health Digital Platform for real-time surveillance, risk assessment, and coordinated decision-making
- **Climate Adaptation:** Develop climate-resilient disease surveillance and control strategies to address the changing transmission patterns of diseases.
- **Global Partnerships:** Expand strategic collaboration with **WHO, FAO, WOAH, UNEP, and regional One Health networks** to align with global standards and enhance cross-border disease preparedness.

Conclusion

The Mission marks a **shift towards integrated and preventive health governance**. Through coordinated action across human, animal, and environmental sectors, it can strengthen India's resilience against zoonotic diseases, antimicrobial resistance, and future pandemics while promoting ecological security.

4.6. NOBEL PRIZE IN PHYSIOLOGY OR MEDICINE 2025

Why in the News?

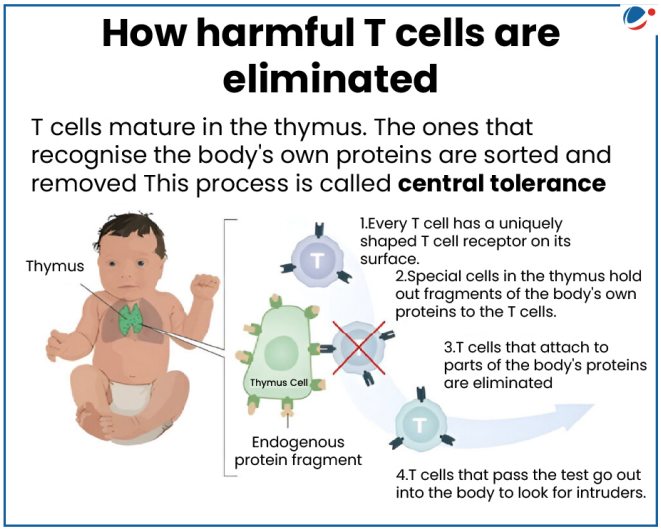
Mary E. Brunkow, Fred Ramsdell and Shimon Sakaguchi have been awarded Nobel Prize in Physiology or Medicine 2025 for their discoveries concerning peripheral immune tolerance.

About Immune system

- Our **immune system** protects the body from harmful pathogens like viruses, bacteria, and fungi.
  - However, it must also make sure **not to attack its own cells** — this balance is very important for healthy body function.
- The immune system uses **two types of tolerance** to achieve this — **central tolerance** and **peripheral tolerance**.

Central Tolerance

- This process happens in the **thymus**, a small gland in the lymphatic system that produces and trains T cells (a type of white blood cell).
- During training, the thymus removes **self-reactive T cells** — these are harmful cells that could attack the body's own proteins. (see infographic)
- However, this process is not perfect. Some of these self-reactive T cells **escape from the thymus** and enter the body's circulation and tissues, known as the **periphery**.


How harmful T cells are eliminated
T cells mature in the thymus. The ones that recognise the body's own proteins are sorted and removed This process is called central tolerance
Thymus
Thymus Cell
Endogenous protein fragment
1.Every T cell has a uniquely shaped T cell receptor on its surface.
2.Special cells in the thymus hold out fragments of the body's own proteins to the T cells.
3.T cells that attach to parts of the body's proteins are eliminated
4.T cells that pass the test go out into the body to look for intruders.

Peripheral Tolerance

- Once in the periphery, **additional control** is needed to prevent escaped self-reactive T cells from attacking the body.
- Here, **Regulatory T cells (Treg cells)** play a key role.
  - **Shimon Sakaguchi** discovered this special class of T cells.
- These patrolling regulatory T cells **identify self-reactive T cells** and **stop them** from attacking our own tissues.
- In this way, Treg cells act as a **security guard**, protecting the body from its own overactive immune responses.

Role of the FOXP3 Gene

- **Mary Brunkow** and **Fred Ramsdell** discovered the **FOXP3 gene**, which **controls the development and function** of regulatory T cells in human body.
- If there is a **mutation in the FOXP3 gene**, regulatory T cells do not form properly.
- This can cause a **rare autoimmune disease called IPEX**, where the immune system attacks the body's own tissues.

Significance of the Discovery

- **Treatment of Autoimmune Diseases:** In a patient suffering from such diseases, increasing the number of regulatory T cells can significantly supress the self-attacking behaviour of immune system.

- **Providing Cancer Treatment:** In cancer, regulatory T cells are often **found in large numbers around tumours**, where they **suppress the activity of immune cells (like killer T cells)** that would otherwise attack the cancer.
- **Other Similar Applications**: Preventing organ transplant rejection, Type 1 diabetes, Asthma, Skin related diseases.

T cells

- **T cells** are a type of **white blood cell** that protects our body from infections.
- **Types of T cells**:
  - **Cytotoxic T cells:** kill cells infected with viruses and bacteria, and they also destroy tumour cells.
  - **Helper T cells:** Don't kill cells directly. Instead, they send signals that tell other cells in your immune system how to coordinate an attack against invaders.
  - **Regulatory T cells:** They Regulate immune responses by suppressing excessive T-cell activity and preventing attacks on the body's healthy cells.
  - **T-cell receptors (TCRs):** Surface proteins that act as sensors, enabling them to detect whether the body is under attack.

4.7. MRNA VACCINES

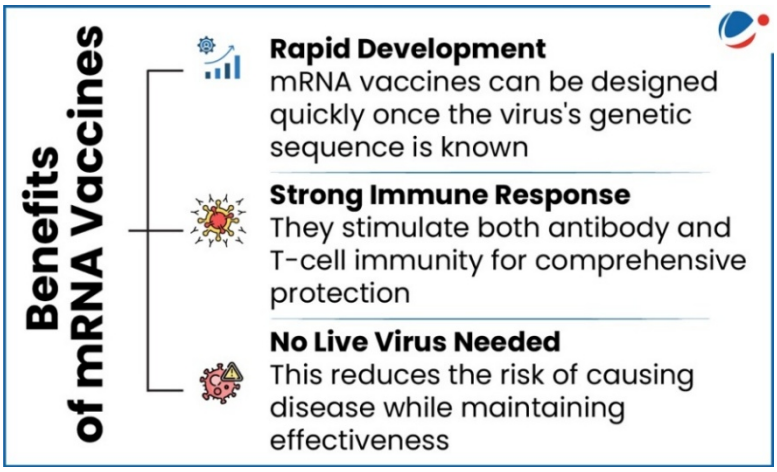
Why in the News?

Russia's personalized mRNA cancer vaccine Enteromix shows 100% success in early trials.

About oncolytic vaccine Enteromix

- It **uses oncolytic viruses (OVs)** to directly **kill cancer cells and stimulate an anti-tumor immune response.**
- **Enteromix** is based on a **combination of four non-pathogenic viruses** that have the ability to destroy malignant cells and simultaneously **activate the patient's antitumor immunity.**
- **Initial target of vaccine** is **colorectal cancer,** Moreover, promising progress has been made in developing vaccines for glioblastoma and specific types of melanoma.

About Personalized mRNA Vaccines


Benefits of mRNA Vaccines
Rapid Development
mRNA vaccines can be designed quickly once the virus's genetic sequence is known
Strong Immune Response
They stimulate both antibody and T-cell immunity for comprehensive protection
No Live Virus Needed
This reduces the risk of causing disease while maintaining effectiveness

- **Personalized Vaccine:** Based on the genetic analysis of each patient's tumor, a unique vaccine is created that can "teach" the immune system to recognize cancer cells.
- mRNA vaccines are a type of vaccine that **use a small piece of messenger RNA** (mRNA) to instruct our cells to **produce a protein specific to a virus.**
- mRNA delivers genetic material**,** encapsulated in **lipid nanoparticles**, into body to prompt protein production that match up with parts of pathogen called antigens.
  - **E.g.**, the **mRNA** vaccine for COVID-19 directed cells to produce copies of a protein on the outside of the coronavirus known as the spike protein.
- **Immune system sees** these **foreign antigens** as invaders, dispatching **defenders called antibodies and T-cells** and training immune system for potential future attacks.

Challenges of mRNA vaccines:

- **Storage requirements:** Require ultra-cold storage, making distribution difficult.

- **Short-term side effects:** E.g., fever, fatigue, and soreness at the injection site.
- **Long-term safety:** mRNA vaccines are relatively new, so long-term effects are still being studied.

Conclusion

mRNA vaccines have transformed modern vaccinology by enabling rapid, adaptable, and highly effective responses to infectious diseases. Their success during **the COVID-19 pandemic** has opened new frontiers in preventive medicine, cancer treatment, and personalized healthcare**.**

4.8. NATIONAL BLOOD TRANSFUSION BILL, 2025

Why in the News?

National Blood Transfusion Bill, 2025, was introduced in Parliament to **establish a uniform national framework for the regulation of blood banks and transfusion** services across India.

Key Provisions of The National Blood Transfusion Bill, 2025

Dedicated National Law	• It is a **standalone legislation** to regulate the collection, testing, processing, storage, distribution, and transfusion of human blood and blood components.
National Blood Transfusion Authority (NBTA)	• Establishes a **statutory central authority** to oversee blood transfusion services at the **national level.**
Uniform National Standards	• Empowers NBTA to prescribe and enforce uniform standards for **quality, safety, and management of blood and blood components** across all States and UTs.
Mandatory Registration of Blood Centres	• Makes **registration with NBTA compulsory** for all blood centres; registration is **valid for five years** and renewable subject to compliance with prescribed norms.
National Haemovigilance System	• Provides for a national haemovigilance programme to monitor adverse **transfusion reactions and prevent transfusion-transmissible diseases**.
Strict Penal Provisions	• Prescribes stringent penalties for: ○ **Unregistered blood centres**: imprisonment up to **3 years** or fine up to **₹10 lakh**, or both. ○ **Unsafe or contaminated blood transfusion**: imprisonment for **2–5 years** with a minimum **₹5 lakh fine**.
Other Important Provisions	• Includes promotion of **voluntary and non-remunerated blood donation, transitional protection** for existing blood centers. • Central Government **funding support**, and accountability through **CAG audit** and **annual reporting** to Parliament.

Need for the Bill

- **Patient Safety:** E.g. Recently **6 thalassaemic children** in Madhya Pradesh's Satna district contracted human immunodeficiency virus (HIV) through blood transfusions.
- **Fragmented Legal Framework:** Blood transfusion services were **governed by dispersed provisions under Drugs and Cosmetics Act, 1940**, leading to regulatory gaps and inconsistent standards across States.
- **Lack of Uniform National Standards:** Absence of standardised norms for **testing, storage, component separation and advanced matching** resulted in regional disparities and compromised clinical outcomes.

BLOOD TRANSFUSION

Blood transfusion is the process of transferring whole blood or its components from a donor to a recipient to restore blood volume, improve oxygen-carrying capacity or correct deficiencies.

THALASSEMIA

Thalassemia is a hereditary blood disorder characterized by reduced or absent haemoglobin production, leading to chronic anaemia and requiring regular blood transfusions.

- **Unreliable Blood Supply and Infrastructure Gaps:** Seasonal donor shortages, uneven inventory management and lack of advanced facilities **(e.g., leukoreduction, alloantibody detection)** at peripheral blood centres affected access.
- **Urban–Rural and Inter-State Inequity:** Blood banks and storage centres remain **concentrated in urban areas**.

Conclusion

Effective implementation of the National Blood Transfusion Bill, 2025, necessitates **cooperative federalism, strengthening of peripheral blood centres, integration of robust digital and haemovigilance systems, and sustained financial support** to ensure safe, equitable, and reliable blood transfusion services nationwide.

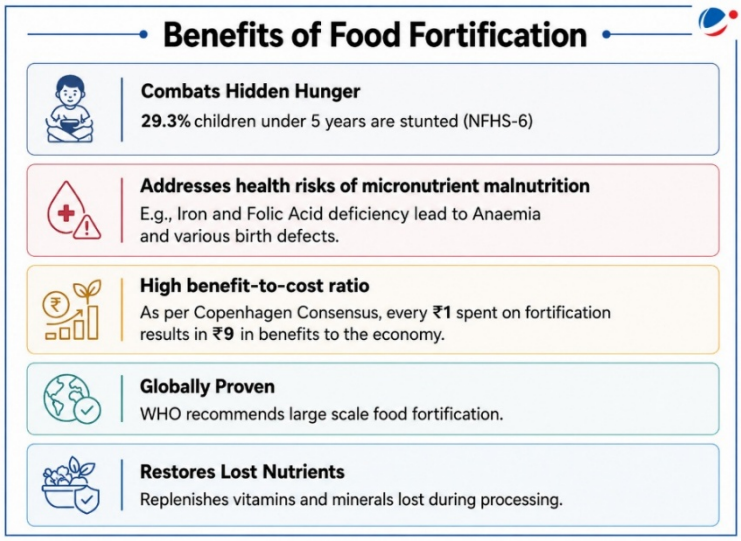
4.9. FOOD FORTIFICATION IN INDIA

Why in News?

Government has temporarily discontinued rice fortification scheme under the **Pradhan Mantri Garib Kalyan Anna Yojana** (PMGKAY) citing findings from an IIT Kharagpur study on nutrient stability.

What is Food Fortification?

- It is deliberately increasing the **content of essential micronutrients** in a food to improve the nutritional quality of food and to provide public health benefit with minimal risk to health.
  - E.g., **Fortified Rice Kernels (FRK)** is produced by blending rice flour with micronutrients such as **Iron**, **Folic Acid (Vitamin B9)** and **Vitamin B12** and shaping it to resemble rice grains.
- **Regulatory Framework in India**: **Food Safety and Standards (Fortification of Food) Regulation, 2018** outlines the standards and quality parameters for fortified foods.
  - Food Safety and Standards Authority of India (FSSAI) has operationalized standards for **fortifying five staple foods: Rice, Wheat Flour, Edible Oil, Milk, and Salt.**
- **Methods of Food Fortification:**
  - **Bio-fortification:** Enhancing the nutritional value of crops while they are being grown, either through conventional plant breeding or genetic modification.
    - > **E.g.,** Vitamin A-rich orange sweet potato.
  - **Industrial Fortification:** Adding micronutrients to staple foods (like flour, oil, and salt) during the manufacturing or processing stage.
    - > **E.g.,** Spraying iodine on salt, or mixing custom-made FRKs into regular rice at a 1:100 ratio.
  - **Home Fortification:** The easiest and most direct method, where individuals manually add micronutrients to their meals.
    - > **E.g.,** Mixing iron sprinkles, powdered nutrient sachets, or tablets directly into food while it is being cooked or right before eating.


Benefits of Food Fortification
Combats Hidden Hunger
29.3% children under 5 years are stunted (NFHS-6)
Addresses health risks of micronutrient malnutrition
E.g., Iron and Folic Acid deficiency lead to Anaemia and various birth defects.
High benefit-to-cost ratio
As per Copenhagen Consensus, every ₹1 spent on fortification results in ₹9 in benefits to the economy.
Globally Proven
WHO recommends large scale food fortification.
Restores Lost Nutrients
Replenishes vitamins and minerals lost during processing.

Concerns Associated with Fortification

- **Lower Bioavailability:** Nutrients added to processed foods often **have lower bioavailability**, reducing their absorption and utilization by the body.
- **Lack of Immune Support:** Unlike natural, whole foods, artificially fortified foods do not contain inherent immune-boosting compounds.

- **Storage Challenges:** Factors such as moisture, temperature, humidity, storage conditions, and packaging significantly affect the stability and shelf life of FRK and Fortified Rice (FR)
- **Risk of Overconsumption:** Excess intake of fortified nutrients may interfere with medications, impair nutrient absorption, and increase health risks.

Way Ahead

- **Dietary diversification: To** tackle both under-nutrition and obesity by encouraging the consumption of a wider variety of nutrient-dense food groups like Millets.
- **Enhanced Labelling**: Food Safety and Standards (Labelling and Display) Regulations, 2020 improve transparency and enable consumers to make informed, healthier food choices.
- **Address concerns about shelf life** by improving packaging, making supply chains shorter and investing in creating more stabilized formulations.

Conclusion

Food fortification is an important tool to address micronutrient deficiencies, but its effectiveness depends on proper implementation and scientific validation. The pause **under Pradhan Mantri Garib Kalyan Anna Yojana** underscores the need for better storage, monitoring, and a balanced approach combining fortification with dietary diversification.

4.10. OBESITY

Why in the News?

World Obesity Federation released World Obesity Atlas 2026, the Atlas provides global, regional and national estimates of rising obesity among children and adolescents.

Driving the rise of Obesity In India
High-Calorie, Low-Nutrient Diets
Increased consumption of refined carbohydrates and saturated fats
Altered Food Composition
Changes in the nutritional makeup of foods impacting metabolism and weight gain
Easy Access to Processed Foods
Widespread availability of packaged, ready-to-eat meals
Physical Inactivity
Declining engagement in sports, exercise, and outdoor activities
Growing Culture of Eating Out
Frequent dining at restaurants where food is often cooked in unhealthy oils
Sedentary Lifestyles
Long hours of sitting, excessive screen time, and minimal movement in daily routines

About Obesity

- **Obesity** is classified by the **World Health Organization (WHO)** as a chronic, relapsing disease characterizing abnormal or excessive fat accumulation that presents a risk to health.
  - Its diagnosis is made by measuring people's weight and height and by calculating the **Body Mass Index (BMI): weight (kg)/height^2 (m^2).**
  - **For school-age children** (aged 5-19 years), obesity is greater than 2 standard deviations above the WHO Growth Reference median.

Key Highlights of the Report

Global Scenario

- **Obesity:** Prevalence of obesity among school-age children **(aged 5-19 years)** has increased from **4%** in 1975 to nearly **20%** in 2022.
- **Implications:** Obesity in childhood frequently persists into adulthood, increasing the risk of Non-Communicable Diseases (NCDs) such as diabetes, heart disease, and certain cancers.
- **High Burden Countries:** Ten countries (with highest burden in China, India, and US) alone account for over 200 million school-age children with high Body Mass Index (BMI).

Indian Scenario

- **High Burden:** India ranks second globally for children who are overweight and living with obesity.
  - **41 million** school-age children in India have high BMI.

- **High chronic disease indicators:** In 2025, about 8.39 million children had BMI-attributed metabolic dysfunction-associated liver disease (MASLD), while **2.98 million** suffered from BMI-attributed hypertension.

Initiatives for Obesity Prevention

- **Fit India Movement:** Promotes active lifestyles and encourages individuals to incorporate fitness into daily routines.
- **Eat Right India:** Ensuring safe, healthy, and sustainable food for all.
- **RUCO** (**Repurpose Used Cooking Oil) Initiative:** Safely repurposes used cooking oil.
- **WHO conditionally recommends GLP-1 therapies** for obesity as part of a broader approach including healthy diet, physical activity, and professional support.

Conclusion

Addressing obesity requires a balanced approach combining lifestyle changes, supportive policies, and community engagement. With collective action and strong political will, we can reduce obesity and build a healthier society.

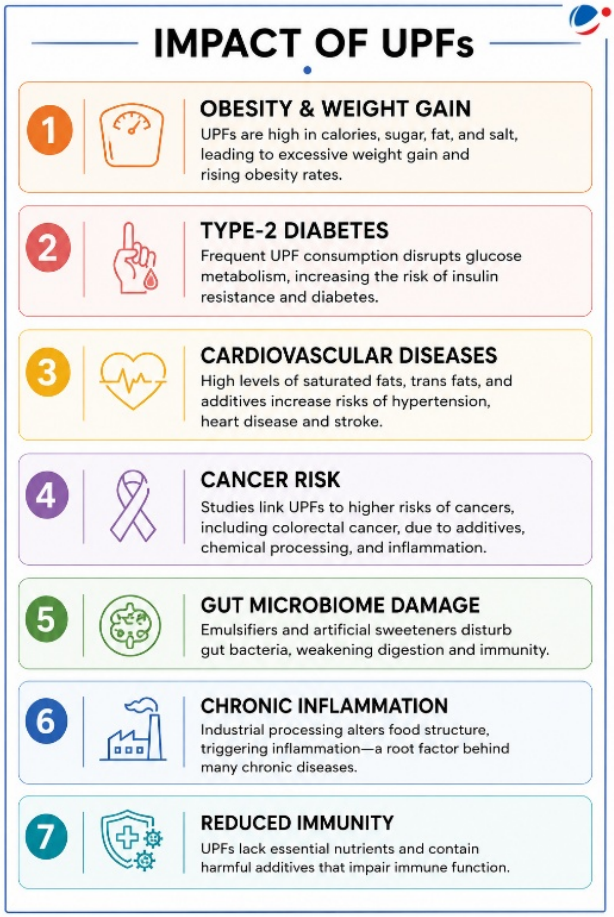
4.11. ULTRA-PROCESSED FOODS

Why in the News?

According to The Lancet Series on **"Ultra-Processed Foods** (UPFs) **and Human Health",** India's modern food environment is driving a rapid rise in obesity and chronic diseases.

Key findings of the report

- **Retail sales of UPFs** rose from **$0.9 billion (2006) to nearly $38 billion (2019) a 40-fold increase.**
- UPFs are accelerating **India's nutrition transition, driving obesity and non-communicable disease (NCDs)** while deepening the **double burden of malnutrition.**


IMPACT OF UPFs
1
OBESITY & WEIGHT GAIN
UPFs are high in calories, sugar, fat, and salt, leading to excessive weight gain and rising obesity rates.
2
TYPE-2 DIABETES
Frequent UPF consumption disrupts glucose metabolism, increasing the risk of insulin resistance and diabetes.
3
CARDIOVASCULAR DISEASES
High levels of saturated fats, trans fats, and additives increase risks of hypertension, heart disease and stroke.
4
CANCER RISK
Studies link UPFs to higher risks of cancers, including colorectal cancer, due to additives, chemical processing, and inflammation.
5
GUT MICROBIOME DAMAGE
Emulsifiers and artificial sweeteners disturb gut bacteria, weakening digestion and immunity.
6
CHRONIC INFLAMMATION
Industrial processing alters food structure, triggering inflammation—a root factor behind many chronic diseases.
7
REDUCED IMMUNITY
UPFs lack essential nutrients and contain harmful additives that impair immune function.

What is UPF?

- They are **industrial formulations,** usually high in **fat, sugar and salt (HFSS),** containing **cosmetic additives** such as **emulsifiers, stabilisers, colourants and flavouring agent**s. E.g., noodles, biscuits, chips etc.
- They are **low in dietary fibre, protein and micronutrients** and are **designed for convenience, long shelf life and hyper-palatability.**

Reasons behind increased use of UPF

- **Urbanisation:** Rapid urbanisation and changing work patterns have reduced time for home cooking**.**
- **Changing Consumption Patterns:** Rising incomes and aspirational lifestyles have increased demand for branded, packaged, and Western-style foods, especially among youth**.**
- **Globalisation of Food Systems**: Global food supply chains have expanded the reach of **multinational brands**.
- **Aggressive Marketing:** Food companies heavily **invest in targeted media advertising, celebrity endorsements and sponsorships**.

- **Policy and Regulatory Gaps**
  - **Weak Food Regulations:** Inadequate restrictions on **marketing, labelling and sale, especially to children, enable unchecked UPF growth.**
  - **Absence of Fiscal Disincentives:** Limited use of **taxation, warning labels and procurement standards reduces incentives** to choose healthier foods.

Initiatives to minimize UPF consumption

- **Consumer Protection Act, 2019** and **Advertising Standards Council of India guidelines aim to curb misleading health claims** and regulate food advertisements, especially those targeting children.
- **Food Safety and Standards (Safe Food and Healthy Diets for School Children) Regulations, 2020** bans advertisements of UPF in school canteens or within 50 metres of school campuses
- **Revised (2024) Dietary Guidelines** for **Indians by the Indian Council of Medical Research.**
- **Economic Survey 2025 proposed health tax on UPFs, stricter labelling, marketing restrictions.**
- **FSSAI limits Trans fatty acids (TFA)** in food products to 2% by mass of total oils and fats.

Way Forward

- **Recognise UPFs as a Public Health Risk**: Integrate the reduction of ultra-processed foods into national nutrition and NCD prevention strategies.
- **Front-of-Pack Warning Labels:** Clear, simple warning labels stating **"high in sugar, salt or fat" should be made compulsory** to help consumers make informed choices.
- **Regulate Corporate Influence**: Voluntary **self-regulation** must be **replaced with enforceable standards, stronger food safety laws** and competition **policies to curb corporate influence.**
- **Restrict UPFs in Public Institutions**: Disallow UPFs in **schools, hospitals, childcare centers, and government facilities.**

Conclusion

The rise of UPFs has emerged as a major driver of obesity and non-communicable diseases, intensifying the country's nutrition and health crisis. Addressing this challenge requires strong **regulatory action, fiscal disincentives**, clear labelling, and sustained public health campaigns to promote healthier dietary choices.

4.12. HEALTH TAX

Why in the News?

World Health Organization (WHO) launched"3 By 35" Initiative to raise prices of any or all of three unhealthy products tobacco, alcohol, and sugary drinks by **at least 50%** through **health taxes by 2035.**

What is Health Tax?

- **Levied on products** that have a **negative public health impac**t. E.g., Tobacco, Alcohol etc.
- **WHO recommends taxation** as one of the most **cost-effective tools for addressing population levels of obesity** and other related non-communicable diseases (NCDs).
- Taxation forms a core pillar of the WHO's "Best Buys" framework for NCD prevention, complementing interventions such as marketing restrictions and nutrition labelling.

Need for Health Tax

- **Health Impact**: Consumption of tobacco, alcohol, and sugary **drinks fuels the NCD epidemic which accounts for over 75% of global deaths.**
- **Economic Impact:** These products create negative externalities **(costs to others) and internalities (hidden costs to consumers).**
  - Tobacco use alone costed the global economy **US$ 1.4 trillion in 2012.**
- **Revenue Generation: 50%** tax can generate up to **US$ 3.7 trillion in new revenue globally within five years**, or an average of **US$ 740 billion per year – equivalent to 0.75% of global GDP.**

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- **Promote Equity:** As NCDs impact **lower-income populations disproportionately.**
- **Existing GST in India** does not differentiate between healthy and unhealthy beverages.

Challenges in implementing a Health tax

- **The substitution effect:** Consumers, Children and teenagers especially, may switch to other high-calorie drinks that are relatively inexpensive.
- **Tax evasion:** Consumers may try to avoid paying diet-related taxes through cross-border purchases. **E.g.** saturated fat tax in Denmark, led Danes to purchase non-taxed products across the border.
- **Impact on Industries:** E.g., Fat tax was abolished in Denmark and Finland due to opposition from industry.

Successful Global Case Studies

Colombia (2016): Higher cigarette tax led to 34% drop in consumption	**Saudi Arabia:** 50% Sugar-Sweetened Beverages (SSB) tax cut consumption by 19% in one year

Steps taken by India

- **Tobacco and Tobacco related products:** GST increased from 28% to 40%.
- **High-fat sugar Salt (HFSS)** foods in India are taxed at a 12% GST rate.
- **Aerated beverages in India** are taxed at 28% GST and an additional 12% Compensation cess.
- **Fat Tax of Kerala:** Kerala had also introduced a fat tax in 2016, which later got incorporated into Goods and Services Tax in 2017.

Conclusion

The success of a health tax lies not merely in its imposition but in its careful design, phased implementation aligned with broader tax reforms, continuous monitoring of its impact on consumption patterns, and complementary measures such as marketing restrictions on unhealthy foods and beverages.

4.13. TRADITIONAL MEDICINES (TM)

Why in News?

Second WHO Global Summit on Traditional Medicine held in New Delhi, India

More on the News

- The Summit is being jointly organized by the **World Health Organization (WHO) and the Ministry of Ayush, Government of India.**
- The **Delhi Declaration** on Traditional Medicine with the Theme - **"Restoring Balance: The Science and Practice of Health and Well-being"** was adopted in the closing ceremony of the Summit.
  - The Declaration focuses on **integrating traditional medicine into primary health care, strengthening regulation and safety standards, investing in research, and building interoperable data systems to track outcomes.**

AYUSH Systems

Characteristic	Ayurveda	Yoga & Naturopathy	Unani	Siddha	Homeopathy	Sowa-Rigpa
Origin	**India**	**India**	**Greece**	**India**	**Germany**	**India**
Focus	Healthy living, personalized healing	Harmony between mind and body	Individual temperament	Identification of causes	Natural law of healing	Balance of five elements namely Prithvi, Jal, Agni, Vayu, and Akash

Significance of Traditional Medicines (TM)

- **Primary Healthcare:** Estimates suggest up to 80% of the world's population relies on TM for primary needs.

- **Vasudhaiva Kutumbakam:** This philosophy of "the world is one family" drives the effort to share TM for global harmonious wellness.
- **Economic Dimension:** India's AYUSH sector is valued at $43.4 billion and has expanded nearly eight-fold in the past decade.
- **Soft Power:** For India, Ayurveda and Yoga serve as significant instruments of cultural diplomacy and soft power on the global stage.
- **Aligning with Sustainable Development Goals (SDGs):**
  - **SDG 3 (Good Health):** Making healthcare more equitable and affordable.
  - **SDG 15 (Life on Land):** Recognizing and valuing biodiversity through the demand for medicinal plants
  - **SDG 17 (Partnerships):** Fostering collaboration through the exchange of ancient knowledge.

Challenges in Promoting Traditional Medicine

- **Standardization Gap:** The lack of uniform global regulatory frameworks for such products leads to quality variations.
  - **Eg:** Indian Ayurvedic products (**like Ashwagandha or Triphala**) vary widely in active compounds across brands due to differing process of manufacturing.
- **Threat to Biodiversity:** Over-exploitation of natural resources for herbal medicines threatens ecological balance and the survival of rare medicinal species.
  - **Eg: Sarpagandha** known for medicinal properties is now classified as an **endangered** species in IUCN Red Data List.
- **Scientific Validation:** Many remedies lack the rigorous clinical trial data required by the mainstream medical community.
  - Eg: **Echinacea** which is widely used for preventing or treating the common cold. Clinical trials investigating it did not show statistically significant reductions in illness occurrence.
- **Intellectual Property Rights (IPR):** Current IPR systems favour individual/corporate ownership, which conflicts with the collective, perpetual nature of traditional knowledge.
  - **Eg**: Patent was granted in the United States for the use of turmeric for wound healing (later revoked).

Initiatives for Traditional Medicine in India

- **National AYUSH Mission (NAM) 2014:** Centrally Sponsored Scheme strengthens infrastructure, services & co-location of AYUSH facilities.
- **Ayurgyan:** For research & capacity building, drug standardisation, medicinal plant research etc.
- **Ayurswasthya Yojana:** Financial assistance for establishing and upgrading functions & facilities and/or for research & development activities in Ayush.
- **AOGUSY (AYUSH Oushadhi Gunvatta evum Uttapadan Samvardhan Yojana):** Focus on drug quality, standardisation & pharmacovigilance.
- **Traditional Knowledge Digital Library:** TKDL contains information from Indian Systems of Medicine.
- **Global Collaborations: MoUs with Indonesia** on quality assurance and **Cuba** on Ayurveda, while announcing a **Centre of Excellence** at the BIMSTEC Summit.
- **Other:** WHO Global Traditional Medicine Centre (GTMC), located in Jamnagar, Gujarat.

Way Forward

- **Scientific Validation:** Bringing evidence-based validation to TM to ensure safety and effectiveness for a global audience.
- **Sui Generis IPR:** Developing a unique IPR system designed specifically to protect collective traditional knowledge.
- **Conservation:** Implementing both *in-situ* and *ex-situ* conservation strategies to protect endangered medicinal plants.
- **Inclusive Research:** Incorporating ethical frameworks that respect the rights of indigenous people and their self-determination.

Conclusion

Indian traditional knowledge offers a holistic reminder that true wellness is a journey of nurturing the entire being—mind, body, and spirit—in harmony with nature.

4.14. ORGAN AND TISSUE TRANSPLANTATION

Why in the News?

According to **Ministry of Health and Family Welfare (MoHFW),** number of organ transplants **increased nearly fourfold** over past decade from **fewer than 5,000 in 2013 to almost 20,000 in 2025.**

About organ transplantation

- It refers to the **grafting of any human organ** from any living person or deceased person to some other living person for therapeutic purposes.
- **Organ Transplantation**: Includes kidney, liver, heart, lung, pancreas, and intestine etc.
- **Tissue Transplantation:** Involves corneas (eye), skin, bone, heart valves, and blood vessels etc.
- **Status:** Presently, India ranks **third** in the world in terms of total Organ Transplantation and **first** in terms of total living donor organ transplantation.

Organ Transplantation Framework in India

- **Legal Framework: Transplantation of Human Organs and Tissues Act, 1994 (THOTA)** enacted by the MoHFW.
- **Regulatory Mechanism: Three-tiered structure** under THOTA, 1994:
  - **NOTTO:** It operates a unified digital registry, allowing voluntary pledging, recipient wait-list management, and near-real-time updates accessible via a web portal and mobile app.
  - **Regional Organ and Tissue Transplant Organization (ROTTO).**
  - **State Organ and Tissue Transplant Organization (SOTTO).**
- **National Organ Transplant Program (NOTP):** Central Sector Programme to improve access to organ transplantation for needy citizens.

Challenges in Organ Transplantation in India

- **India faces a low deceased organ donation** rate of less than **1 per million population** (Spain **52.6** per million population in 2024).
- **Slow progress**: Number of donors (including deceased) only grew from 6,916 in 2014 to about 18,911 in 2024 (NOTTO).
- **Supply-demand Mismatch:** Organ Transplant Waitlist in India Stands at 89,839 as on March 3, 2026.
- **Brain stem death declaration:** As brain death has been defined only in connection with organ donation in the THOTA, 1994 and not in Registration of Births and Deaths Act, 1969.
- **Other:** Organ trafficking, family veto, lack of male donor participation (70%-75% of donors are female), etc.

Initiatives taken for organ transplantation

- **One Nation One Policy**: State domicile, age limits, and registration fees removed for deceased donor organ transplant recipients.
- **Aadhaar-linked digital pledge portal**: It was launched in September 2023, enabling over **3 lakh citizens to register their pledges** for organ donation.
- **Angdaan Jan Jagrukta Abhiyan** was launched in 2024.
- **State initiatives: E.g.,** Platforms like **Telangana's Jeevandan** have successfully digitized recipient scoring (weighing dialysis duration, age, immunological criteria).

Way forward

- **Adopting an opt-out model of organ donation system,** prevalent in countries like **England, Singapore,** etc.

- Under it, the deceased patient **is presumed to have consented** to organ removal.

- **Emulate Kerala model in other states:** Kerala has become the first State to formulate well-defined clinical protocols for brain death certification.
- **Transparency in Organ Allocation:** Creation of digital registry on organ transplantation to enhance transparency.
- **Streamline transportation process: For e.g.,** In air mode, Consistent use of flight notes to indicate organs on board, so that air traffic control can ensure priority take-off and landing of aircraft.

Conclusion

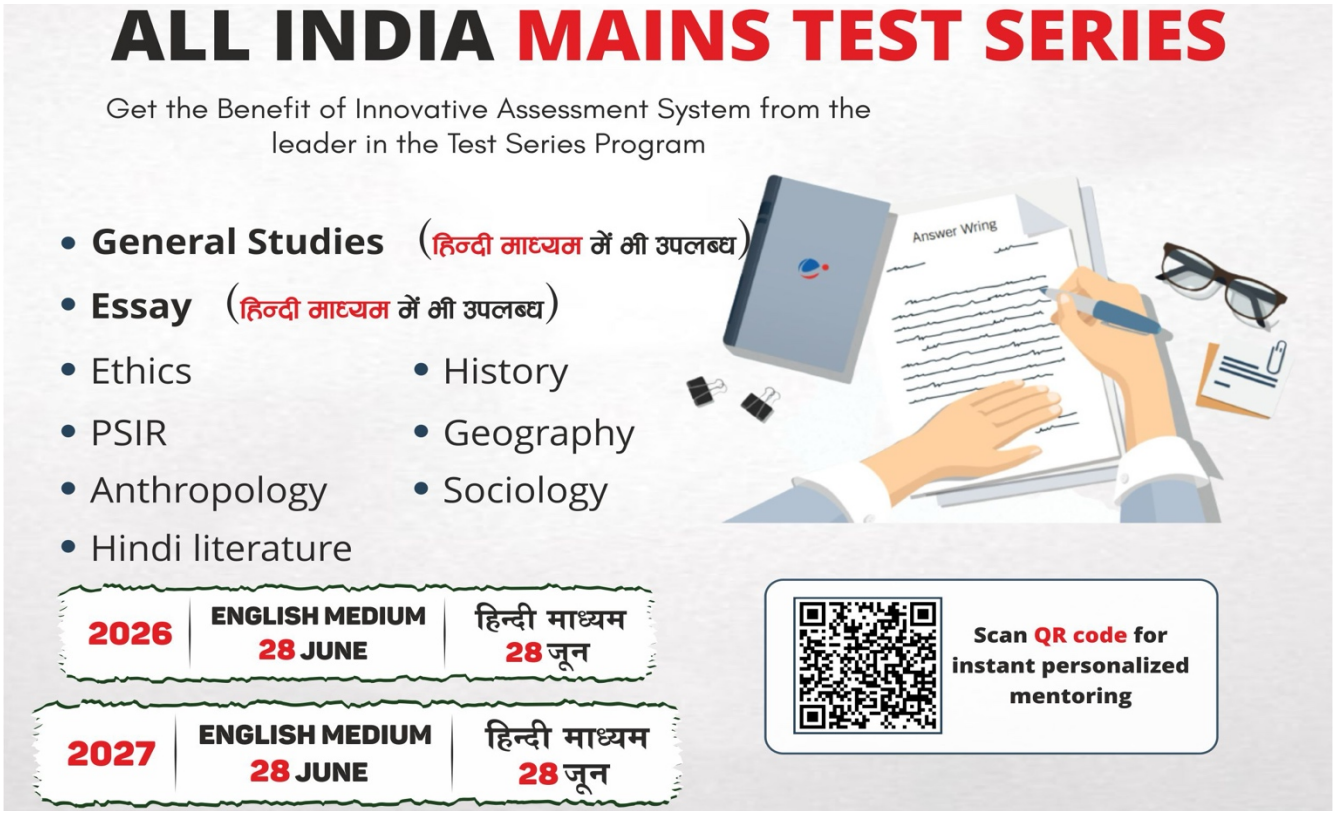
Organ and tissue transplantation is a life-saving medical intervention that enhances survival and quality of life. Strengthening awareness, ethical donation practices, robust healthcare infrastructure, and equitable access can help bridge the demand–supply gap and advance the vision of a healthier and more compassionate society.

4.15. KEY WORDS

Keywords			
Antimicrobial Resistance (AMR)	**Non-communicable Diseases (NCD)**	**Tuberculosis (TB)**	**mRNA Vaccines**
Traditional Medicines (TM)	**Obesity**	**Food Fortification**	**Human Papillomavirus (HPV)**
FOXP3 Gene	**T cells**	**NOTTO**	**One Health**

4.16. PRACTICE QUESTION

Organ transplantation is a critical component of modern healthcare. Discuss the challenges associated with organ transplantation in India and suggest measures to bridge the demand–supply gap.			
Introduction	**Body Part 1**	**Body Part 2**	**Conclusion**
Organ transplantation and its status.	Challenges in Organ Transplantation in India	Measures to Bridge the Demand–Supply Gap.	Value-Added Conclusion.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5. MISCELLANEOUS

5.1. NUCLEAR ENERGY IN INDIA AT A GLANCE

Nuclear Energy in India

Nuclear energy, currently uses controlled atomic fission to release heat, which is used to generate electricity

Installed Capacity: 8.78 Gigawatt (GW) in 2024–25 and projected to reach **22.38 GW** by **2031–32.**

Why India must scale Nuclear Energy?

Ensuring Energy Security: Nuclear power provides a reliable domestic source of baseload electricity, reducing dependence on imported fossil fuels.

Meeting Climate Commitments: Nuclear energy is a low-carbon source of electricity and is essential for achieving India's target of **Net Zero by 2070.**

Meeting energy demands: India needs to increase its power generation capacity four-fold to **2100 GW** by **2047** against an anticipated demand of **708 GW.**

Optimizing Land Use: A **1,000 MW** nuclear power plant typically requires only a few square kilometres of land, whereas generating the same electricity from solar power may require **40–75 times** more land.

Reducing Air Pollution: Replacing coal-based electricity with nuclear power can significantly reduce particulate matter, sulfur dioxide, and nitrogen oxide emissions.

Initiatives taken to promote Nuclear Energy

Atomic Energy (Amendment) Act, 2015: It Enable **NPCIL** to form joint venture with other Indian PSUs to meet funding requirements for expansion of nuclear power programme.

International Cooperation for assured Uranium supply India signed civil nuclear cooperation agreements with **18 countries** like Canada, Kazakhstan, etc. E.g., **US–India nuclear deal 2008.**

Nuclear Energy Mission: To achieve **100 GW** of nuclear power capacity by **2047.**

SHANTI Act, 2025 It brings together various elements of nuclear development under a single, comprehensive structure.

Challenges related to Nuclear Energy

Safety and Accident Risks: Increased public fear especially after 2011 Fukushima disaster in Japan, difficult radioactive waste management.

Dual use nature of uranium: Generally, greater than **20 % U-235** is used in commercial nuclear reactors. However, highly enriched uranium is largely used for nuclear weapons.

Import Dependency: India remains heavily dependent on uranium imports, producing less than **1%** of global output —with major imports from Kazakhstan, Canada, Uzbekistan, and Russia.

Other: High capital costs and long gestation period, water Intensive Operations etc.

Way Forward to Increase Nuclear Energy

Develop a National Fuel and Waste Framework: For spent fuel management and radioactive waste disposal, alongside strengthening fuel supply chains.

Adopt a Dual-track Technology Strategy: India's nuclear roadmap should explicitly integrate large-scale reactors and small modular reactors **(SMRs)** as complementary rather than competing technologies.

Innovate Financing Mechanisms: To balance private investment with state oversight, the government should use project-specific Special Purpose Vehicles **(SPVs)** led by NPCIL.

Benefit sharing: Link nuclear projects to local community development, ensuring that residents see direct benefits in terms of infrastructure, employment, and energy access.

5.1.1. THE SHANTI ACT, 2025

Why in the News?

The President has granted assent to the Sustainable Harnessing and Advancement of Nuclear Energy for Transforming India (SHANTI) Bill, 2025.

More on the News

- It aims to create a **unified Legal Framework** by consolidating existing laws into a single, comprehensive statute, thereby enhancing regulatory clarity and investor confidence.
- It repealed the **Atomic Energy Act (AEA), 1962** and the **Civil Liability for Nuclear Damage Act (CLNDA), 2010.**

Key Features of the Act

Private Sector Participation	• It permits **private companies, joint ventures or any other person expressly permitted by the central government** to participate in India's nuclear sector, enabling them to undertake: ○ **Plant operations,** power generation, equipment manufacturing, and selected activities such as the fabrication of nuclear fuel including conversion; ○ **Refining and enrichment of uranium-235** up to such threshold value, or production, use, processing or disposal of other prescribed substances.
Activities Under Exclusive Central Government Purview	• Certain **sensitive nuclear fuel-cycle activities** are reserved exclusively for Central Government or its wholly owned institutions. ○ These include **enrichment of radioactive substances**, **management of spent fuel,** etc.
Grants Statutory status to Atomic Energy Regulatory Board (AERB)	• To strengthen regulatory independence and authority. ○ **AERB** was **constituted in 1983** under the **AEA**, and is now answerable to Parliament rather than solely to the executive. ○ It is responsible for **ensuring nuclear safety, radiation protection, emergency preparedness,** and quality assurance across civilian nuclear installations.
New Civil Liability Framework	• Introduces a **clear graded liability** system for nuclear operators. • **Liability caps:** ₹3,000 crore (large plants), ₹1,500 crore (medium), ₹100 crore (SMRs). ○ Government bears liability beyond the cap through a **Nuclear Liability Fund.** • **Removes supplier liability** completely (unlike CLNDA, 2010, which allowed claims for defective equipment).
Regulation of Non-Power Applications	• Provides a regulatory framework for the use of nuclear and radiation technologies in **health care, agriculture, industry, research**, and other peaceful applications.
Licensing and Safety Oversight	• Establishes a structured system for **granting, suspending, or cancelling licences and safety authorisations** for nuclear energy production and use.
Central Government Acquisition Rights	• **Vests exclusive acquisition rights** with the Central Government in specific cases related to nuclear activities.
Dispute Redressal Mechanism	• Establishes an **Atomic Energy Redressal Advisory Council** to facilitate the redressal of disputes.
Nuclear Damage Claims Commission	• Provides for a dedicated **Commission** to handle cases involving severe **nuclear damage** and **ensure timely adjudication**.

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Territorial Scope of Compensation	• **Extended to nuclear damage** in foreign territories caused by incidents in India, subject to specified conditions.
Appellate Tribunal Provision	• **The Appellate Tribunal for Electricity**, set up under the **Electricity Act, 2003**, will serve as the appellate authority.

Why is there a need to open the Nuclear Sector for Private Entities?

- **Increasing share of Nuclear Power:** Nuclear power has accounted for around 3% of total electricity generation.
- **Resource Mobilisation**: Private participation expands capital availability, attracting domestic and global investment.
- **Delay in Completion of Project**: E.g., Prototype Fast Breeder Reactor at Kalpakkam, originally scheduled to be commissioned in 2010.
- **Advanced technology access:** Private sector entry accelerates the adoption of advanced technologies such as **Small Modular Reactors (SMRs)**, modular reactor designs and modern safety systems.
- **Facilitating Clean energy transition:** To meet the national target of 100 GW nuclear capacity by 2047 and advance long-term decarbonisation by 2070.

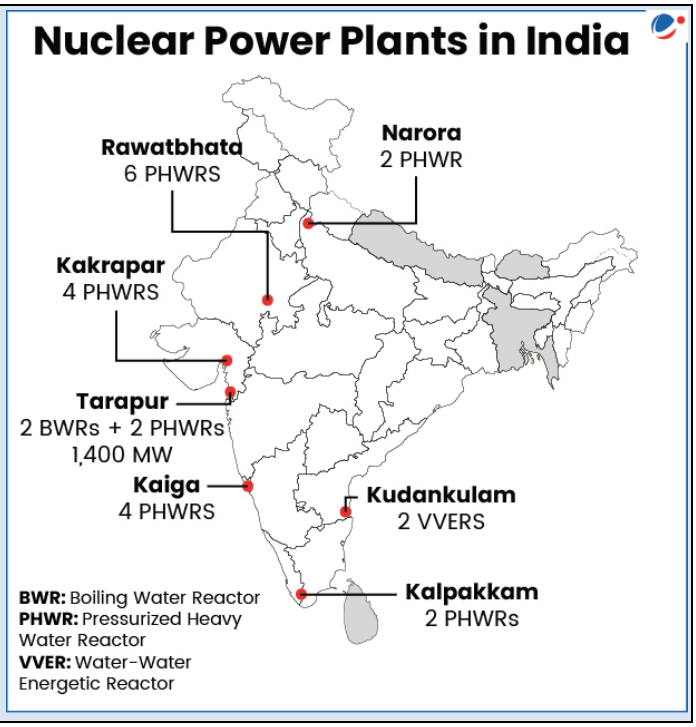
Conclusion

By modernising the legal framework and strengthening institutional oversight, it creates the foundation for a more efficient, innovative, and secure nuclear ecosystem.

Related News

Mahi Banswara Rajasthan Atomic Power Project

- PM laid the foundation of the Mahi Banswara Rajasthan Atomic Power Project (MBRAPP).
- **Location**: Banswara, Rajasthan near the Mahi Dam on River Mahi.
- **Capacity**: 4 x 700 MWe PHWR (4 nuclear power units of Indigenous PHWRs (Pressurized Heavy Water Reactors)).
- **It will be developed by Anushakti Vidhyut Nigam (ASHVINI)**, a joint venture between Nuclear Power Corporation India Limited (NPCIL) and National Thermal Power Corporation Limited (NTPC).
- The project is part of India's "**fleet mode**" initiative.
  - Under this **Initiative**, ten identical 700 MW reactors are being built across India under uniform design and procurement plans.



5.1.2. FAST BREEDER REACTOR (FBR)

Why In the news?

India's indigenously designed and built 500-Megawatt electric Prototype Fast Breeder Reactor (PFBR) at Kalpakkam in Tamil Nadu attained criticality advancing the 2nd stage of the 3-stage civil nuclear programme.

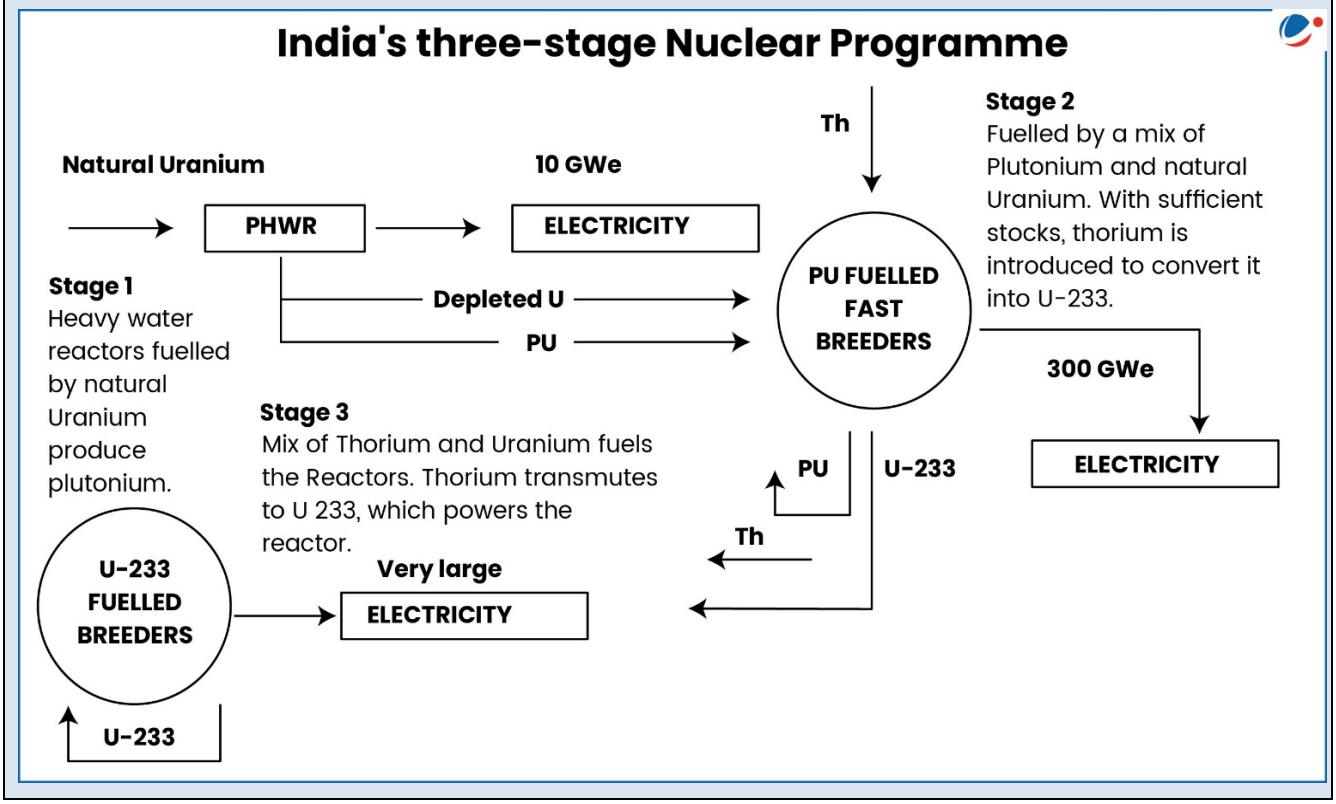
About Fast Breeder Reactor (FBR)

- Nuclear reactor that uses **fast neutrons** to **generate more nuclear fuels** than they consume while generating power.

- **Developed by:** Indira Gandhi Centre for Atomic Research, an R&D center under Department of Atomic Energy.
- **Operated by:** Bharatiya Nabhikiya Vidyut Nigam Ltd **(BHAVINI**), a public ltd. Company under Companies act 1956 under Department of Atomic Energy (DAE) to pursue construction, and operation of FBRs.
- **Criticality:** Stage where a reactor achieves self-sustaining chain reaction with neutrons produced by fission equalling those lost at absorption and leakage enabling sustained power output.
- **Significance of FBR**
  - **Paves way for third stage**: It also marks use of Thorium-232 (a non-fissile material), which creates fissile **Uranium-233** to be used as **fuel in third stage.**
  - **Technological Advancement**: India becomes **second country** after Russia with a commercial FBR.
  - **Reduced Nuclear Waste:** The spent fuel generated by the PFBR will be reprocessed and recycled back into the reactor.
  - **Utilization of Thorium Reserve:** Paves the way for the **full utilization** of India's abundant thorium reserves.

India's 3-Stage Nuclear energy Programme

- **Conceived by** Dr. Homi Jehangir Bhabha, architect of India's nuclear programme.
- Designed by **Department of Atomic Energy**.



Conclusion

Like Russia and China**,** India can develop HALEU (High-Assay Low-Enriched Uranium) fuel which makes less waste and generate extreme heat and will be required by Future Advanced reactors and SMRs. Additionally, Diversify Import partners and further explore domestic Uranium sources for short term Autonomy.

5.1.3. THORIUM BASED REACTOR

Why in the News?

China successfully achieved the first-ever thorium to uranium fuel conversion in a Thorium Molten Salt Reactor (TMSR).

About Thorium Molten Salt Reactor (TMSR)

- It is **fourth-generation** advanced nuclear energy system that uses **high-temperature molten salt** as a **coolant**.
- **Key Features**: Cool without water, **run** at **atmospheric pressure**, deliver a **high-temperature output**, etc.
- **Key Advantages**:
  - **Passive Safety Features**: If an MSR is too hot, a salt plug melts, stopping the reaction.
  - **Small High-Level Nuclear Waste Footprint**: Thorium generates fewer long-lived minor actinides (radioactive metallic elements) than plutonium fuels.
  - **Other**: Extract more energy from fuel, etc.

Thorium Fuel

- **Thorium** has to be converted to **Uranium-233** in a reactor before it can be used as fuel.
  - Thorium-232 is the only naturally occurring isotope of thorium.
- It is **three times more abundant** in nature than uranium.
  - Despite its widespread availability, the metal's utilisation is restricted by its high extraction cost.
- Also, India is developing an **Indian Molten Salt Breeder Reactor (IMSBR)**.

Significance of Thorium based reactors

- **Abundant Supply unlike Uranium.** In India, Kerala and Odisha have rich reserves of monazite, which contains about 8 – 10% thorium.
- **Chemically safe,** due to higher melting point, better thermal conductivity, better fuel performance characteristics, chemical inertness and stability.
- **Environmentally safe,** generates lesser toxic and short-lived radioactive wastes.

Conclusion

The development of thorium-based molten salt reactors marks a significant shift towards safer, cleaner, and more sustainable nuclear energy. With abundant thorium reserves and superior safety features, these reactors present a promising alternative to traditional uranium-based systems

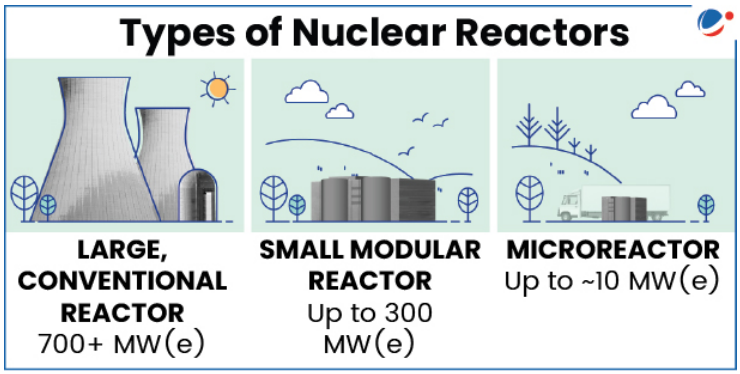
5.1.4. SMALL MODULAR REACTORS (SMRS)

Why in the News?

India developing three different types of Small Modular Reactors (SMRs).

About Small Modular Reactors (SMRs)

- SMRs are advanced nuclear reactors that **have a power capacity of up to 300 MW(e) per unit**, which is about **one-third of the generating capacity** of traditional nuclear **power reactors** (IAEA).
- SMRs, which can produce a large amount of low-carbon electricity, are:
  - **Small:** Physically a fraction of the size of a conventional nuclear power reactor.
  - **Modular:** Making it possible for systems and components to be factory-assembled and transported as a unit to a location for installation.
  - **Reactors:** Harnessing **nuclear fission** to generate heat to produce energy.



SMRs of India

- While SMRs are an entirely new concept, **Bharat Small Reactors (BSRs)** are based on **India's existing PHWR (Pressurized Heavy Water Reactor) technology.**
- **3 SMRs models being developed by Department of Atomic Energy (DAE):**

- **Bharat Small Modular Reactor (BSMR) 200MWe:** Indigenously developed by **Bhabha Atomic Research Centre (BARC)** (unit of DAE and **Nuclear Power Corporation of India Limited (NPCIL).**
- **Based on PWR technology**; slated to utilize **Slightly Enriched Uranium (SEU)** as fuel to be constructed at **Tarapur Atomic Power station site, Maharashtra.**
- **SMR-55MWe**: Also modelled on PWR technology, featuring a block-type, highly modular design to be constructed at **Tarapur.**
- **Up to 5 MWth High temperature gas cooled reactor:** Meant for **hydrogen generation** to be constructed at BARC Vizag, Andhra Pradesh.

Significance of SMRs for India

- **Reduced fuel requirements**: Require less frequent refuelling, every **3 – 7 years**, compared to 1 -2 years for conventional plants.
- **Scalability:** Deployed **Incrementall**y as per increased energy demand.
- **Safer: Inherent and passive safety features** entailing no human intervention to shut down the system.
- **Reduces Wastage**: Eliminate or significantly lower the potential for unsafe releases of radioactivity to the environment.
- **Reduce land requirement:** Their smaller capacity and footprint also make them **well-suited for deployment** in locations with smaller grids where constructing massive traditional nuclear plants is not feasible.
- **Others:** Low carbon energy; cater to higher energy demand in the wake of rise Artificial Intelligence, etc.

Conclusion

Small Modular Nuclear Reactors hold significant promise as a flexible, safer, and more cost-effective alternative to traditional large nuclear plants. By offering scalable clean energy solutions with enhanced safety features, SMRs can play a vital role in meeting growing energy demands and reducing carbon emissions.

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5.1.5. NUCLEAR FUSION AT A GLANCE

Nuclear Fusion

Nuclear Fusion occurs when two atoms slam together to form a heavier atom, like when two hydrogen atoms fuse to form one helium atom.

Fuel used: Generally, two hydrogen (H) isotopes- deuterium (D) and tritium (T).

Why India needs to promote Nuclear Fusion?

Higher Energy:
Generates four times more energy per kilogram of fuel compared to nuclear fission.

Accessible Fuel:
Deuterium extracted from seawater, with abundant lithium.

Intrinsically Safe:
Not expected to produce high activity or long-lived nuclear waste.

Initiatives taken to promote Nuclear Fusion

ADITYA:
Institute of plasma research, Ahmedabad indigenously built and operated the first Indian Tokamak.

Steady State Superconducting Tokamak (SST-1)
for developing an experimental facility to study plasmas in steady state in thermo-nuclear fusion devices.

Indus Synchrotron Radiation Facility:
INDUS-1 and INDUS-2 share a common injector system consisting of a microtron and a booster synchrotron.

China's Experimental Advanced Superconducting Tokamak (EAST):
It maintained a steady-state high-confinement plasma.

Other Global:
Joint European Torus (**JET**) in UK, Korea Superconducting Tokamak Advanced Research (**KSTAR**) in South Korea.

Challenges related to Nuclear Fusion

High temperature required:
Temperatures of over **100 million °C** are required to make deuterium and tritium fuse (**IAEA**).

Magnetic Confinement:
The plasma must be suspended within a confined space using strong magnetic fields to prevent contact with reactor walls.

Neutron radiation:
During the reaction can travel tens of centimetres out into containment structure which can cause structural damage.

Measures required to promote Nuclear Fusion Energy

International cooperation:
It can play key role in achieving the **net Energy Gain (NEG).**

Invest in R&D:
To develop radiation-resistant and heat-tolerant materials for reactor walls and components.

Accurately evaluate: The plasma confinement magnetic field using **AI technology** that solves optimization problems.

5.1.5.1. INTERNATIONAL THERMONUCLEAR ENERGY REACTOR (ITER)

Why in the News?

India's contribution to ITER for fusion research has been maintained at Rs.745 crore in B.E. 2026-27.

International Thermonuclear Energy Reactor (ITER)

- **ITER** is **world's largest tokamak** launched as an international joint experiment in fusion, located in **Southern France.**
- **ITER** is a **magnetic fusion device** that has been designed to prove the **feasibility of fusion** as a large-scale and carbon-free source of energy based on the same principle that powers our Sun and stars.
- **Primary Objective**: Investigation and demonstration of burning plasmas.
  - **Plasmas** in which the energy of the **helium nuclei** produced by the fusion reactions is enough to maintain the temperature of the plasma, thereby reducing or eliminating the need for external heating.
- **Working Principle:** TER work on the "Tokamak" concept where the reaction of **hydrogen isotopes Deuterium and Tritium** produces energy by the **mass-energy conversion principle**, thereby proving to be a source of unlimited energy.
- **Members:** 27 members of European Union (EU), China, India, Japan, Korea, Russia, United States and Switzerland.
  - **EU** contributes **45% of construction cost** while rests of the parties contribute 9% each.
- **India's Membership:** India joined the ITER project in **2005.**
  - **Institute for Plasma Research in Ahmedabad** is lead institution from India participating in the project.

About Tokamak Reactors

- **Purpose:** The tokamak is an experimental machine designed to harness the energy of fusion.
- **Working:** Inside a tokamak, fusion plasma is created and confined by strong magnetic fields.
  - Plasma is a fundamental state of matter along with solids, liquids and gases.
- **Energy to electricity:** The energy produced through the fusion of atoms in the plasma is absorbed as heat in the walls of the vessel.
- **Just like a conventional power plant,** a fusion power plant will use this heat to produce steam and then electricity by way of turbines and generators.

Conclusion

ITER is one of the most complex scientific and engineering projects in the world today. The complexity of the ITER design has already pushed a whole range of leading-edge technologies to new levels of performance. However, further science and technology are needed to bridge the gap to the commercialization of fusion energy.

Related News

Fusion-Fission Hybrid Reactor

- China aims to construct the **World's First Hybrid Fusion-Fission Nuclear Plant**, named Xinghuo.
- **About Fusion-Fission Hybrid Reactor**
  - **Concept:** Uses **high intensity neutron flux** produced by a **fusion reactor** to drive a **nuclear fission reaction**, and breed **fissile fuel from fertile materials.**
  - **Design:** Contains a **nuclear fusion reactor core** where **deuterium** and **tritium nuclei** are fused to form **helium** and a **fast neutron,** surrounded by a **blanket** of **fertile material** (like uranium-238 or thorium-232).
  - **Fuel Supply:** Hybrid reactor would **produce enough fissile fuel** through breeding.
    - The fusion neutrons can **convert fertile materials** into **fissile materials** (like plutonium-239 or uranium-233) increasing fuel supply.

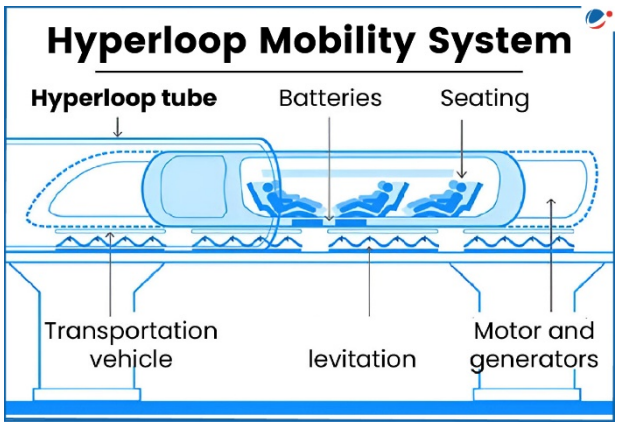
5.2. HYPERLOOP TECHNOLOGY

Why in the News?

Maharashtra inks deal with IIT Madras startup (TuTr Hyperloop Pvt Ltd) to build hyperloop.

Hyperloop Mobility System

- **Genesis**: In 2013, the CEO of SpaceX, **Elon Musk,** proposed a concept of **ultra-high-speed rail (UHSR)** called hyperloop and open-sourced it.
- **About**: It is basically a **magnetic levitation (maglev) system** where pods travel at **ultra-high speeds through low-pressure tubes.**
- **Functioning:**
  - Hyperloop functions in a **sealed tube with minimal air resistance**, utilizing **vacuums** and **magnetic levitation** for hovering.
  - **Linear Induction Motors (LIM)** propels pods silently enabling the theoretical speed of 1,200 km/h.
- **Key components**: **Steel tubes** (100Pa pressure), pressurized capsules, a **compressor** for airflow, and **air bearing suspension.**



- **Advantages of Hyperloop**
  - **High Speed**: Ultra-high speeds (e.g., Mumbai-Pune in 25 mins).
  - **Driverless:** Eliminates human error.
  - **On-Demand:** 10–30 sec intervals, no collision risk.
  - **Weatherproof:** Less affected by weather, no track buckling.
  - **Less Invasive:** Easier tunnels, smaller stations.
  - **Reshapes Logistics:** Carries large containers, cuts truck emissions.
  - **Cuts Emissions:** 2–3 times more efficient, uses maglev and low-pressure design, stores electricity.
- **Issues with Hyperloop technology**
  - **High Costs:** ~$25–$27 million per mile (excluding land costs) as per NASA.
  - **Safety Concerns:** Fire inside pods is a major risk despite fire-resistant tubes.
  - **Vacuum Maintenance:** Energy-intensive and challenging over long distances.
  - **Acceleration Impact:** Lateral/vertical acceleration >2 m/s^2 can cause motion sickness.
  - **Infrastructure Demand:** Needs long, straight, stable tracks are difficult to construct

Conclusion

Hyperloop system is the superb alternative for transportation instead of today's expensive and slow transportation systems. Substantial financial backing, continuous research and development complemented by new regulatory frameworks are crucial for overcoming technical and safety challenges of hyperloop technology.

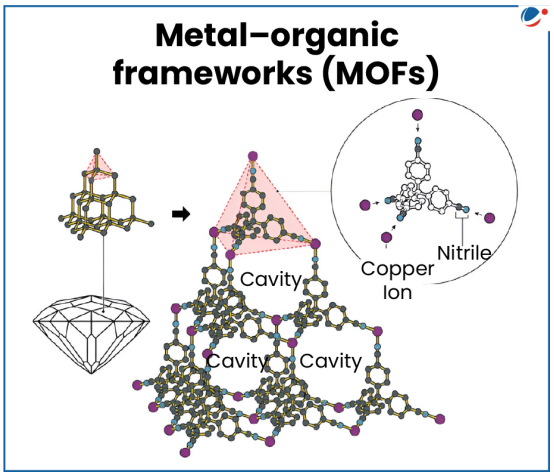
5.3. NOBEL PRIZE IN CHEMISTRY 2025

Why in the News?

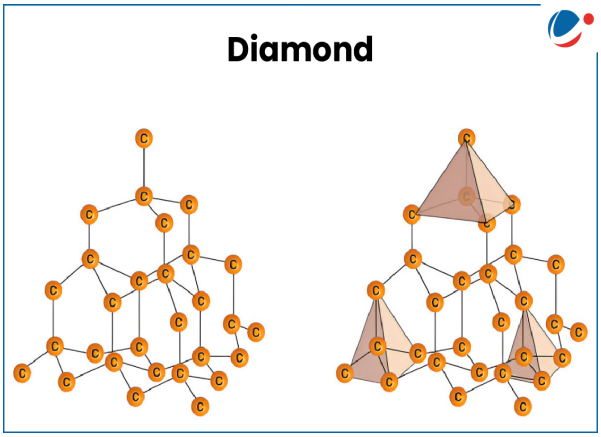
Susumu Kitagawa, Richard Robson and **Omar M. Yaghi** are awarded the Nobel Prize in Chemistry 2025 for the development of **metal–organic frameworks.**

More on the News

What is Metal–Organic Framework (MOF)?



- MOFs are special materials made up of **two parts**:
  - **Metal ions (such as copper, etc.)** – this act like the "joints" or "connecting points"
  - **Organic molecules (carbon-based molecules like coal, etc.)** – these acts like the "links" or "bridges" that connect the metal parts together.
- When **metal ions** and **organic molecules** join through chemical bonds, they form a **network structure.**
- The cavities inside the network make the material **highly porous**- full of tiny holes inside. **(See infographic)**
- The idea to create MOFs came from studying the **structure of diamond** - in which each carbon atom connects to four others, forming a small pyramid-like pattern.



Key Features

- The **pores or cavities** inside MOFs can be made **bigger or smaller** by changing the metals or the organic molecules used.
- **This means MOFs** can be **customized** to absorb or trap specific kinds of materials like gases, water, or chemicals.
- They act like **molecular storehouses**, storing gases, liquids, or other materials inside their pores.

Key Applications

- **Water Harvesting:** MOFs can capture water vapour from desert air during the night and releasing potable water in morning heat.
- **Healthcare:** They are proving instrumental in **delivering pharmaceuticals** in the body, **managing extremely toxic gases**, and encapsulate enzymes that break down traces of antibiotics in the environment.
- **Food Processing**: MOF-based packaging materials absorb excess ethylene gas released by fruits and vegetables after harvesting, thereby slowing ripening and spoilage and increasing their shelf life.
- **Removal of Pollutants:** They can filter out harmful substances like Perfluoroalkyl and Polyfluoroalkyl Substances (PFAS), and catalyse decomposition of crude oil and antibiotics in polluted water.
- **Industrial Applications:** Can be used for mining rare-earth elements from wastewater, store hydrogen, and capture carbon dioxide.
- **Gas storage**: Storing gases such as hydrogen, carbon dioxide, methane etc.

Conclusion

The 2025 Nobel Prize in Chemistry highlights how advanced materials like MOFs can drive sustainable development by addressing challenges in energy, water, and climate change.

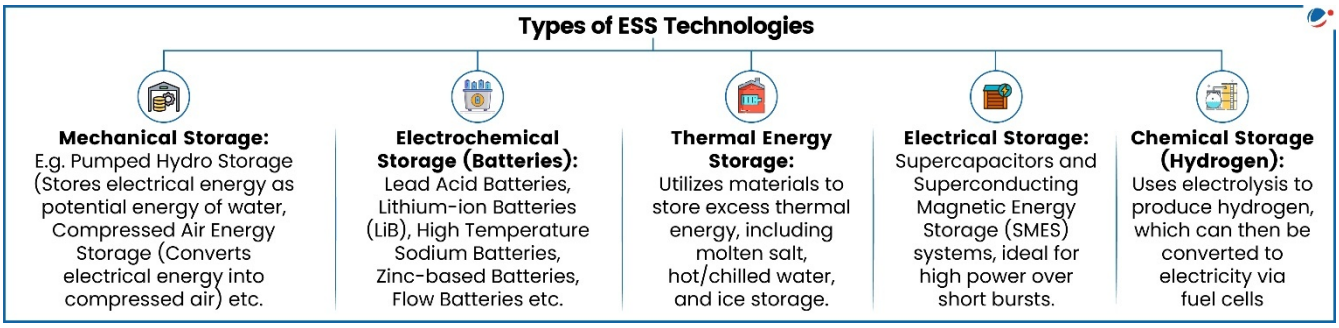
5.4. ENERGY STORAGE SYSTEM (ESS)

Why in the news?

Report by India Energy & Climate Centre highlighted that India requires $50 billion new investment in Energy storage System by 2032.

About Energy Storage Systems (ESS)

- **ESS** can be used for storing available energy from Renewable Energy and can be used during peak hours of day.
- **Need:** Central Electricity Authority estimated that the required energy storage capacity by **2029-30** is **60.63 GW** (18.98 GW from Pumped Storage Projects and 41.65 GW from Battery Energy Storage Systems (BESS)).


Types of ESS Technologies
Mechanical Storage: E.g. Pumped Hydro Storage (Stores electrical energy as potential energy of water, Compressed Air Energy Storage (Converts electrical energy into compressed air) etc.
Electrochemical Storage (Batteries): Lead Acid Batteries, Lithium-ion Batteries (LiB), High Temperature Sodium Batteries, Zinc-based Batteries, Flow Batteries etc.
Thermal Energy Storage: Utilizes materials to store excess thermal energy, including molten salt, hot/chilled water, and ice storage.
Electrical Storage: Supercapacitors and Superconducting Magnetic Energy Storage (SMES) systems, ideal for high power over short bursts.
Chemical Storage (Hydrogen): Uses electrolysis to produce hydrogen, which can then be converted to electricity via fuel cells

Significance of ESS in India

- **Minimizes greenhouse gas emissions:** Aid in achieving Panchamrit target of **net zero emission** by 2070.
- **Reduce Energy Costs:** Stored energy can be used **during peak hours**, when energy prices are highest.
- **Renewable Energy Integration**: Enables higher penetration of Variable Renewable Energy (VRE) into the grid.
- **Supports Electric Vehicle (EV) Ecosystem:** ESS can facilitate fast-charging infrastructure and manage charging loads.

Initiatives taken to Promote ESS in India

- **National Framework for Energy Storage Systems (2023):** Released by the Ministry of Power for the development and deployment of Energy Storage Systems to facilitate energy transition in India.
- **Legal status for Energy Storage Systems (ESS):** It has been issued by Ministry of Power in 2022 **wherein** ESS has been designated as a Power System element which can be utilized as a Generator, Transmission or Distribution element**.**
- **Energy Storage Obligation trajectory till 2029-30**: It has been notified by Ministry of Power in 2022.
- **Viability Gap Funding (VGF) scheme**: For development of 4,000 MWh of BESS projects by 2030-31.
- **Production Linked Incentive Scheme** for National Programme on Advanced Chemistry Cell Battery Storage.

Challenges associated with ESS in India

- **Dependence on Critical Mineral Imports:** Extremely low reserves of Raw materials like lithium, cobalt, nickel and battery-grade graphite.
- **Policy uncertainty:** Such as discontinuation of tax holidays, reduction of accelerated depreciation benefit, etc.
- **Land Issue:** Pumped Storage Projects (PSPs) may involve land acquisition, displacement, and ecological impacts.
- **Other challenges:** Lack of high-quality R&D infrastructure, Absence of EV and storage policies.

Policy and Regulatory Recommendations

- **Adding Storage to Existing RE Projects:** Maximize grid infrastructure efficiency and address regulatory challenges.
- **Mandatory Co-located** Energy Storage for New RE Projects
- **Expanding Viability Gap Funding (VGF):** Extend existing VGF scheme for standalone Battery Energy Storage Systems (BESS) to solar + storage projects.

- **Promoting Domestic Manufacturing and Supply Chains:** Expand schemes like PLI program specifically targeted at advanced chemistry cells (ACC) and R&D.

Conclusion

Propelling Energy Storage System (ESS) would not only aid in evolving clean energy systems but could also help establish India as a hub for cutting-edge research and innovation, boost manufacturing capabilities, create new jobs, and foster economic growth.

5.4.1. LITHIUM-ION (LI-ION) BATTERY

Why in the News?

India's Largest Lithium-ion (Li-ion) Battery Manufacturing Plant was inaugurated in Haryana.

More on the News

- When fully complete, it will produce about **20 crore** battery packs every year, covering **nearly 40% of India's annual requirement of 50 crore packs**.
- It was established under the Centre's **Electronics Manufacturing Cluster (EMC) scheme**.

About Li-ion Battery

- It is a type of **rechargeable battery** where lithium ions move between a negative electrode (graphite) and a positive electrode (Li transitional metal oxides) through a non-aqueous electrolyte during charging and discharging.

Benefits of Lithium-ion Batteries

- **High energy density**: At 75-200 Watt-hours /KG, stores more energy compactly, and offers **longer cycles** between charges.
- **Lightweight and Lower Toxic Heavy Metals**: Compared to older **lead-acid batteries**, it is much lighter due to use of less toxic and lightweight **Li and carbon electrodes**.
- **Excellent performance**: They provide **good cycle stability, efficiency, and reliability**, with low self-discharge and generally **no memory effect (**slow-down due to repeated charging**)**.

Challenges

- **Supply Chain Vulnerability: E.g.,** China controls half of global Li production and 70% of Li-ion battery production.
  - India imported Li-ion batteries worth **US$ 1.2 billion (2018-2022).**
- **Safety hazards**: They contain a **flammable electrolyte**, which can lead to explosions if manhandled.
- **Environmental impact**: E.g., Lithium mining is **water-intensive** (Apprx. 2,000 tonnes per tonne of lithium).
- **Lack of Recycling Units** exacerbates the issue of safe disposal.

Conclusion

Lithium-ion batteries are at the heart of the global clean energy transition, powering electric mobility and renewable energy storage. Strengthening domestic manufacturing, securing critical mineral supply chains, and advancing battery recycling will be crucial for ensuring sustainable and resilient energy systems.

5.4.2. NEXT GENERATION BATTERY TECHNOLOGIES

Why in the News?

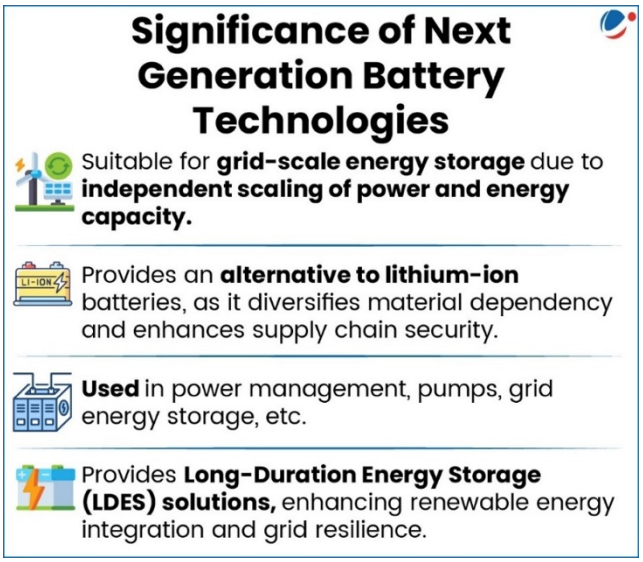
India's largest and first MWh-Scale Vanadium Redox Flow Battery (VRFB) inaugurated at NTPC NETRA.

More on the News

- **Flow Batteries**, along with **solid state batteries**, are one of the next generation battery technologies and are emerging as an **alternative to lithium-ion** for grid-scale applications, offering **flexibility, longevity, and safety.**

About Next Generation Battery Technologies

- **Flow Batteries:** Flow batteries are powered by **reduction-oxidation (redox) reactions** and involve **two different liquid electrolytes** that pass ions or protons back and forth through a porous membrane.
  - These batteries can **store larger amounts of energy**—as much as the size of the electrolyte cells can contain—and don't use flammable or polluting materials.
  - **Types of Flow Batteries:** Vanadium Redox, Zinc–Bromine, Iron–Salt/Organic systems.
- **Solid-State Batteries:** These use **solid electrolyte solutions**, which don't need a different separator.
  - It **makes them safer** because they are less prone to leakage from damage or swelling in hot temperatures.


Significance of Next Generation Battery Technologies
Suitable for grid-scale energy storage due to independent scaling of power and energy capacity.
Provides an alternative to lithium-ion batteries, as it diversifies material dependency and enhances supply chain security.
Used in power management, pumps, grid energy storage, etc.
Provides Long-Duration Energy Storage (LDES) solutions, enhancing renewable energy integration and grid resilience.

Conclusion

Next-generation battery technologies are poised to redefine the future of energy storage by delivering safer, more efficient, and sustainable alternatives to lithium-ion batteries. Their successful commercialization will be critical for advancing clean energy transitions, electric mobility, and long-term energy security.

5.5. RARE EARTH ELEMENTS

Why in the News?

Union Cabinet has approved the "Scheme to Promote Manufacturing of Sintered Rare Earth Permanent Magnets (REPMs)" to secure India's long-term supply of rare earth magnets and reduce dependence on imports.

Key Features of Scheme

- **Objective:** Establish 6,000 Metric Tons per Annum (MTPA) of integrated REPMs manufacturing in India.
- **Beneficiaries Allocation:**
  - **The 6,000 MTPA capacity** will be allocated to five beneficiaries through global competitive bidding.
  - **Each beneficiary** may receive up to 1,200 MTPA capacity.
- **End-to-End Manufacturing Integration:** It supports the creation of facilities that cover the **complete processing facilities**: -
  - **Rare earth oxides → metals→ alloys→ finished rare earth permanent magnets**
- **Rare Earth Permanent Magnets (REPMs)** are among the strongest types of permanent magnets, known for their high magnetic strength and stability.

What are Rare Earth Elements (REE)?

- **Rare-earth elements** are a group of **17 metallic elements in** the periodic table, comprising **15 lanthanides, scandium, and yttrium.**
  - **Despite the name "rare,"** most REEs are relatively abundant in the Earth's crust, but they are rarely found in economically exploitable concentrations**.**
  - **Characteristics:** These elements share similar properties such as **high density and high conductivity**.
- **Source:** Main sources of **REEs** are minerals such as **bastnasite, loparite and monazite**.
  - India holds **13.15 million** tonnes of monazite, containing an **estimated 7.23 million tonnes** of rare-earth oxides (REO).
- **Exploration outcomes**: The Geological Survey of India has identified **482.6 million tonnes** of rare-earth ore resources through exploration projects.

- **Ministry of Mines has included all REEs** in the list of **critical minerals,** it will cover all types of ores of REE including Monazite.
- **Applications:** Laptops, LED Monitors/TVs, Smartphones drive trains, wind, chemical catalysts, glass manufacturing, specialized glass lenses, armoured vehicles, night vision goggles etc.

Need of Rare Earth Elements (REE)

- **Self-Reliance (Atmanirbhar Bharat**): By reducing dependence on imports, where 60–80% of the value and 85–90% of quantity of permanent magnets were sourced from China between 2022–25.
- **Clean Energy Transition:** Rare earth magnets are essential for electric vehicle motors and wind turbine generators, both central to India's renewable energy expansion and its Net Zero 2070 vision.
- **National Security and Defence:** Rare earth magnets are vital for aerospace systems, defence equipment, and precision sensors.
- **Economic & Electronic**: Essential for semiconductor chips in smartphones, computers, and communication devices.

Initiatives launched for REE production

- **Launch of the National Critical Mineral Mission (NCMM):** Announced in Budget for 2024-25, to secure India's critical mineral supply chain.
- **The Mines and Minerals (Development and Regulation) Amendment Act, 2023:** Now allows private companies to bid for the exploration of critical minerals, including REEs.
- **Bilateral and Multilateral Cooperation:** Such as **India-Australia Critical Minerals Investment Partnership,** for co-investing in Australian Rare Earth Element (REE) projects.
- **Exploration efforts: Department of Atomic Energy** discovered around **huge source of in-situ Rare Earth Elements Oxide (REO**) in **Balotra, Rajasthan**.
- **India-US Sign Framework** on "Securing of Supply in the Mining and Processing of Critical Minerals and Rare Earths"

Conclusion

To reduce dependence on China for rare earth elements (REEs), countries may build strategic inventories, boost domestic production, and invest in advanced refining technologies. Deep-sea exploration and recovery from secondary sources offer additional supply avenues. Streamlined regulations and private sector incentives are essential to accelerate self-reliance in the REE value chain.

5.6. KAVACH

Why in the News?

The Kavach system has now been implemented on more than **2,200 route kilometres,** helping **reduce train accidents** sharply, from 135 in 2014–15 to 31 in 2024–25, and further to 11 in 2025–26.

About Kavach

- It is an indigenously developed **Automated Train Protection (ATP) system** that provides **Train Protection** and **Collision Prevention capabilities** for trains
- **Developed by:** Research Designs & Standards Organization (RDSO) of Indian Railways.
- **Working Principle**: Continuous real-time communication between trackside systems and locomotives using secure Ultra High Frequency (UHF) radio antenna and track-mounted Radio Frequency Identification (RFID) tags.
- **Continuous improvements:** Adopted as the **National Automatic Train Protection (ATP)** system in **2020, Kavach Version 4.0** approved in **2024**.

Advantages of Kavach

- **Detection and prevention** of **Signal Passing at Danger (SPAD)**: Automatically stops the train before the signal.
- **Cab signaling** with display of movement authority, target distance, speed, and signal aspects.
- **Prevention of all types of train collisions:** head-on, rear-end, and side-on.
- **Automatic horn activation** when approaching Level Crossing Gates.
- **Emergency Stop-on-Sight (SoS)** messages in critical situations.
- **Centralized live monitoring of train movements** through the Network Management System (NMS).

Other Technology-led and AI Railway Safety Initiatives

- **AI-enabled Intrusion Detection System (IDS)** based on Distributed Acoustic Sensing (DAS) technology to detect the presence of wild animals on railway tracks.
- **AI-driven Predictive Maintenance** and Inspection Video Surveillance System (VSS),
- **GPS-based Fog Safety Device (FSD)** is provided to Loco Pilots in fog-affected areas, enabling them to know the distance to approaching landmarks such as signals and level crossing gates.
- **Optical Fibre Cable (OFC) Network:** As of October 2025, 619 route kilometres of OFC were laid, taking cumulative coverage to approximately 67,233 route kilometres.

Conclusion

With the combined deployment of Kavach 4.0, the upcoming Kavach 5.0, and AI-driven monitoring systems, Indian Railways is actively building a modern, integrated, and predictive safety architecture. These technologies are strengthening operational reliability, protecting passengers and staff, safeguarding infrastructure, enhancing suburban capacity, and improving wildlife safety.

5.7. KEY WORDS

Keywords			
Nuclear Energy	**Fast Breeder Reactor (FBR)**	**Small Modular Reactors (SMRs)**	**Hyperloop**
Rare Earth Elements	**Lithium-ion (Li-ion) Battery**	**Flow Batteries**	**Tokamak**
Nuclear Fusion	**Kavach**	**Metal–Organic Framework (MOF**	**Thorium Molten Salt Reactor**

5.8. PRACTICE QUESTION

Discuss the key provisions of the SHANTI Act, 2025. Why is there a need to open the Nuclear Sector for Private Entities?			
Introduction	**Body Part 1**	**Body Part 2**	**Conclusion**
Objective of SHANTI Act, 2025	Key Provisions of SHANTI Act, 2025.	Need to Open Nuclear Sector for Private Entities.	Futuristic Conclusion

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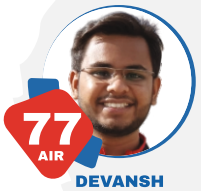
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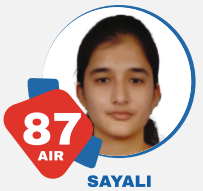
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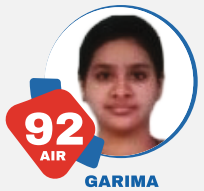
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